Relative Costs of U.S. and Foreign Nodule Transport Ships

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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Office of Policy and Planning
Marine Minerals Division

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for

U.S. DEPARTMENT OF COMMERCE
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ABSTRACT: This contract report contains the results of a study to identify the relative cost differences of U.S. and foreign transport ships of the types which could be used to transport manganese nodules from a deep seabed mining area to shore for processing. This study was performed for the Marine Minerals Division (MMD) of NOAA's Office of Policy and Planning as an extension of a MMD project to assess the potential environmental, social, and economic impacts of manganese nodule processing activities. This study is based, in part, on information from the published contract report Description of Manganese Nodule Processing Activities for Environmental Studies (three volumes). This report considers relative costs of acquiring and operating nodule transport ships which are U.S. built and operated, foreign built and U.S. operated, and foreign built and operated. It estimates total costs for a typical nodule transport service in the Pacific Ocean, including consideration of world and U.S. shipbuilding prices, capital cost recovery, nodule handling equipment, cargo transfer facilities, crew and passenger accommodations, wages and benefits, insurance and reserves, maintenance and repair, overhead and administration, fuel and port charges, and typical routes and operating schedules.

AVAILABILITY: The report is available through the U.S. Department of Commerce's National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22151 (telephone: 703-557-4600). Other related reports available through NTIS (order by accession number when given) include: Description of Manganese Nodule Processing Activities for Environmental Studies (three-volume set: PB 274 912/SET), and per volume as follows: Volume I, Processing Systems Summary (PB 274 913/AS); Volume II, Transportation and Waste Disposal Systems (PB 274 914/AS); and Volume III, Processing Systems Technical Analyses (PB 274 915/AS).

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PREFACE

This report had been prepared for the Office of Marine Minerals of the National Oceanic and Atmospheric Administration of the Department of Commerce under Contract 7-73775 of June 24, 1977. NOAA has undertaken the Deep Ocean Mining Environmental Studies (DOMES) project studies to assess the potential impacts of deep ocean mining of manganese nodules in the Central Pacific, and to develop environmental safeguards. In a complementary series of projects, a three-phase program is underway to assess the environmental and social and economic impacts of other activities associated with the nodule mining industry, including processing, waste disposal, and ship and land transportation. This report is a small part of the first phase studies, and includes all the material prepared under this contract.

This study was conducted and report written by Benjamin V. Andrews, a consultant and naval architect in Menlo Park, California. Important contributors to the cost data prefer to remain unidentified, however their significant assistance is gratefully acknowledged.

Project monitors at NOAA were Mr. Amor Lane and Mr. Karl Jugel, whose cooperation and advice accelerated the performance of this analysis and is most appreciated.

August 19, 1977

The *Orread*, chartered to Marcona Corp., a 33,242 DWT ore or oil carrier unloading by slurry one experimental hold of iron ore at Portland, Oreg., in 1970. This Japanese-built ship has a 544' length overall, 625' between perpendiculars, 87.17' beam, 87' depth, and 35.43' draft. Her steam turbines generate 11,250 shaft horsepower to achieve a 14.5-knot loaded speed.

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INTRODUCTION AND SUMMARY

BACKGROUND

The deep ocean mining of manganese nodules may begin in exploratory volumes within a few months, and possible large scale commercial mining could commence in the early 1980s. The mining sites of commercial interest are usually in international waters beyond the jurisdiction of any country. Vessels will be needed to transport nodules from the mining ship to a marine terminal and ultimately to a processing plant for recovery of nickel, cobalt, copper, and in some plants, manganese. The costs of acquiring and operating the ore transport vessels will depend upon where they are built and the nationality of the operators. The purpose of this study is to estimate these cost differences.

Throughout the Merchant Marine Act of 1936, commerce is described as domestic when it is between ports of the United States and it territories, or alternatively as foreign when between foreign ports or between United States and foreign ports. Locations on the high seas are not defined as ports of any nationality. Only American owned, built, and manned ships may be used in domestic commerce. Any foreign ship, and American ships, can engage in foreign commerce. American ships in foreign commerce may qualify for construction and operating subsidies.

If the nodule carriage to land is defined as a United States domestic cargo movement, then no foreign ship may carry the nodules to United States ports without a waiver; that is difficult to obtain. U.S. ships in domestic trade are not eligible for any construction or operating subsidies, and must be essentially completely built in the United States, manned by Americans and owned by U. S. citizens. Title XI of the 1936 Merchant Marine Act provides Federal Ship Financing Guarantees which should be available to assist operators in obtaining reasonably priced, long term ship financing. However the use of a Capital Construction Fund, which permits net income tax to be deferred on monies set aside for future vessel construction, is questionable unless the movement is suitably defined as in the noncontiguous domestic trade.

If the nodule carriage to land is defined as a foreign trade movement, then both foreign and United States flag ships may carry the nodules to American ports. The foreign built ships could have foreign crew and owners, and are estimated in this study to be much less expensive to build and operate than U.S. ships. American ships <u>may</u> be eligible to receive

Construction Differential Subsidy (CDS) and Operating Differential Subsidy (ODS), which are designed to equalize the costs of U.S. and foreign ships. However, the availability of such government subsidies for this service is not assured. The subsidies must also be proven as essential to meet the foreign competition.

Foreign built vessels may also be imported for registry under U.S. flag, and operated by American crew and owners. However neither CDS nor ODS can be provided for this situation. Total costs would be intermediate in cost between the United States built and operated ships, and the foreign ships.

As part of Phase I of a three-phased assessment of the potential environmental, social and economic impacts of manganese nodule processing activities, the numbers and types of nodule transport vessels needed were estimated, ignoring construction and location manning considerations. These studies are being conducted by the Department of Commerce's National Oceanic and Atmospheric Administration (NOAA). During the course of Phase I, NOAA found that American environmental, social and economic effects could differ, depending on whether the nodule transport ships were U.S. built or not, and operated under United States flag or other flag. Each of the deep seabed mining consortia would reach primarily an economic decision as to location of shipbuilding or conversion, and flag of operation. Therefore NOAA decided to perform this current study as an extension of recent work. The purpose of this report is to determine, in the absence of legislation requiring vessels to be American built and operated, or in the absence of provisions for subsidies, or other measures to encourage use of United States ships, the extent of cost differences in nodule transportation between United States built and operated, foreign built and American operated, and foreign built and operated vessels.

METHOD OF APPROACH

The method of approach chosen for this study was to secure specific construction and operating cost data for conventional foreign and American built ships, to identify the special features and operations needed on nodule transport ships and to estimate their costs, and then to estimate the operating and total costs for the vessels in typical nodule transport service.

The manganese nodule is relatively dense, with a specific gravity of about 2.0 or less in the stowed condition. Ore carrier ship hold configurations are necessary for this density.

Nodules were assumed to be raised from the sea floor with a hydraulic mining system and arrive at the surface as a mixture of nodules, nodule fragments, and seawater. Nodules may also be ground, either at the bottom or at the surface, to form a more easily pumpable slurry. Thus, nodules could be handled as a fine or coarse slurry, or dry of surface water as a mixture of whole nodules and nodule fragments. In this latter case, mining ship to transport ship handling would be accomplished by use of conveyors.

Nodules may be ground and dried to reduce their weight by about thirty percent. Because of potential mining ship problems with drying significant quantities of nodules, with pneumatic handling of dried nodules, and the poor efficiency of fuel used for drying, industry probably would not dry nodules to powder form, unless transportation distances are very long. Therefore this dried nodule alternative was not analyzed in this study.

All methods of handling nodules can be used on conventional standard ore carriers, bulk or ore ships, or ore, bulk or oil (OBO) combination ships.

Recent vessel cost data, other published ship costs and cost indices were collected and combined with data in my private files. Additional sources of information were interviewed to obtain early 1977 data; sources included U.S. and foreign shipyards, the Maritime Administration, and operators of U.S. and foreign vessels. Data was sought for ships meeting the appropriate national classification society and governmental regulations, or international specifications for International Maritime Consultative Organization (IMCO) or Safety of Life at Sea (SOLAS) conferences. The ships in the data collected ranged in size from about 20,000 to 180,000 deadweight tonnage (DWT)*. The engineering characteristics of the ships were not well defined. However vessel type and equipment, speed, machinery and owner were always available. Combination ship dimensions were assumed as typical of recent designs, intermediate between the older, faster hulls and the extremely shallow-draft geometry.

The American ship costs collected excluded United States subsidies, if any. Some data sources were public information, but many were private enterprises unwilling to permit publication of their cost information. Therefore proprietary data are not given, and the tables and graphs do not have a source indicated.

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*For this report, deadweight tonnage is in either metric or long tons that are interchangeable. Deadweight tonnage is the weight capacity of the ship for cargo, fuel, supplies and crew.

For each type of ore-carrying vessel, the yard construction price of conventional ships without special nodule transport features was interpreted from the data for U. S. construction, and for foreign construction in both the Orient and Northern Europe. Long-term prices based upon full costs, not currently depressed prices subsidized by governments to avoid unemployment, were sought but not secured. Both steam and diesel powered ship prices were included. Graphs were prepared showing the yard prices at then-current exchange rates, as a function of ship deadweight. Cost data points adjusted for inflation over time and exchange rate, from a variety of sources and for a variety of ship designs, were then used for a suitable range of ore-carrying ships. By this plotting procedure, small cost differences caused by ship specification variations are smoothed, and approximate cost ranges suitable for the purposes of this report are produced.

The accuracy of the ship cost estimates is limited, because of variables of ship design and quality, number of ships ordered, differences in contract pricing, the fluctuation of exchange rates, and the escalation assumed to equate all yard prices to early 1977 contract dates. Further changes in relative prices can be expected prior to the time ships are ordered by the consortia for delivery in the mid 1980s. Variations of up to one or two million dollars, about five percent, can be expected for a specific ship costs, as compared to the parametric presentation of prices as a function of deadweight tonnage in this report.

The standard ore carrier for port-to-port operation is not adequately equipped to transfer nodules at sea by any method. Equipments for slurry handling and dry conveyors were identified as appropriate. Stowage, receipt, and discharge of the nodule material was evaluated to identify other vessel cargo handling requirements. Three ship designs for dry nodule handling and two for slurry pumping were developed, and handling equipment costs estimated roughly as compared to basic conventional ship costs.

The standard features required in United States ships for pollution control, safety and health will be provided on American ships. Foreign vessels, especially inexpensive standard design carriers from Oriental shipyards, ordinarily would need additional measures to meet the American standards of quality, and these increments were also indentified. A list of specific items needed to comply with high U.S. standards and not on many typical foreign ships was prepared, based on current knowledge of requirements. A price was estimated for the improvements, which estimates are not as accurate as the basic price estimates for conventional ships.

The total purchase price of the nodule transport ship includes the conventional ore-carrying vessel price plus nodule handling equipment, hotel accommodations, safety and pollution control features and quality improvement for a higher standard.

The construction prices were converted to loan amortization including interest, depreciation to a salvage value, taxes at appropriate rates, and earnings of equity and working capital at needed levels for investment. The annual capital recovery rate was applied to the total improved ship cost to compute annual and daily cost allocations. This capital recovery rate corresponds to the cost to a consortia for a long term bareboat charter with a ship owner. An alternate, lower capital recovery rate that excludes earnings on equity was also computed, for application in the case where the consortia owns the ships and evaluates total return on equity invested in the entire mining, transportation, processing and disposal operations.

Operating cost components include fuel, wages and benefits, stores and supplies, maintenance and repair, subsistence, insurance, reserves for claims, crew transportation, lube oil, overhead and administration. These quantities are also estimated for each vessel type and nationality. Fuel costs including lubricating oil were assumed at OPEC cartel prices for the appropriate grade and consumption rate.

For all three flag situations, the costs for identical nodule transport services were estimated on a per voyage, per ton,* and annual basis. Typical transport voyages were simulated for ships of four sizes. Movements of slurry and raw nodules to representative United States Pacific coastal ports at San Pedro, California, and Astoria, Oregon were computed. Assumptions about probable cargo handling rates and ship turnaround time in port and at sea were identified. The magnitude of cost differences between U.S., foreign,and mixed ships is clearly measured. The extent of appropriate U.S. subsidy, if any, can be inferred from the cost differences.

SUMMARY

The next paragraphs briefly describe the analytical results of the study in the four areas of the report: Conventional ore-carrying ship building prices; equipment cost estimates for nodule transport ships; current operating costs; and simulations of nodule transport voyages and their costs.

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*tons (long) and tonnes (metric) are interchangeable in this report.

Ore-carrying Ship Construction Prices: To illustrate the results of the parametric cost analysis, four ship sizes covering the full range of ship deadweight tonnage expected for nodule transport service were selected for computations and are reported here. The gearless standard ore carrier ship yard prices for United States, European and Oriental designs are summarized below. The American ships are steam powered, all others are diesel propelled. United States shipyards could deliver in three years, while the currently under-utilized foreign yards could deliver in two years. No adjustment in price is made for earlier delivery or later order at a higher price.

TABLE I-1

EARLY 1977 SHIPYARD PRICE ESTIMATES FOR ORE-CARRYING SHIPS
(Million Dollars)

	Deadweight Tonnage (DWT)			
Flag/Type	40,000	55,000	70,000	85,000
U.S. Standard/Bulk or Ore, Steam	$38.0	$43.5	$48.0	$52.3
European Standard/Bulk or Ore, Diesel	21.3	25.0	28.3	31.3
Oriental-U.S. Standard/ Bulk or Ore, Diesel	15.4	18.6	21.5	24.0
Oriental-Standard/Bulk, Diesel	11.9	14.1	16.0	17.8

The Oriental shipyard prices are abnormally low, probably well below yard cost, because of the current low demand for new ships and governmental financial support to maintain employment in shipyards. This low price situation could change before nodule transport ships are ordered in the early 1980s, and therefore the European yard typical prices are used as the criterion of true foreign ship purchase costs which may be expected in the 1980s when demand for new ships has revived, delivery times may be more comparable, and governmental intervention is largely reduced.

The capital costs of OBOs are much higher at large deadweight than other ore-carrying ship designs. Because the flexibility to carry oil may not be used often by ships principally used to carry nodules, the extra cost is probably unwarranted and therefore OBOs were not analyzed for operating costs in nodule service.

Nodule Transport Ship Equipment Cost Estimates: The nodule transport service will require special equipment for receiving nodules, and accommodations for the crew of the mining ship carried as passengers. Also, upgrading of some

standard ships to meet the higher quality standards of American owners, and to meet United States navigation, pollution control, safety and health requirements will increase the yard price.

The standard features required in U.S. registered ships for pollution control, safety, and health are provided on all American and many European ships. Many higher quality standards for equipment, materials and construction of American-owned ships are economic choices, and commonly provided on many foreign ships to improve efficiency and reliability. European vessels ordinarily would need very few additional measures to meet the American quality standards. Standard low cost ships from Oriental yards would need upgrading. Specific items needed both to comply with U.S. regulations and to raise standards, and not on typical cheap foreign ships were identified, and a price was estimated for the improvements. For the European ships, expenditures of $1.2 million for 40,000 DWT ship, to $2.2 million for the 85,000 DWT size, would meet all proposed and existing U. S. navigation regulations, provide full unmanned diesel engine room automation and systems checks, meet all air, water, oil, and cargo pollution control requirements, and provide first class crews' quarters. The costs for Orient-built ships to American and foreign standards are shown on Table I-1.

The standard ore carrier for port-to-port operation must be equipped to transfer nodules at sea. Costs of cranes for both loading and discharge, for slurry load and discharge systems, and for conveyors in United States yards are shown on Table I-2. Foreign equipment costs average about two-thirds of the U.S. costs. However installation of slurry discharge pumps or self-unloading conveyor discharge machinery was found to be expensive both to install and maintain, and shore discharge machinery should be more desirable.

Shipboard installations for receiving manganese nodules at sea from the mining ship were selected for conveyor and slurry cargo handling methods. The selected loading-only equipment costs are less than $1 to $3 million in the United States, and much less abroad. These on deck handling equipments are also quickly added to suitable conventional ore-carrying ships, and easy to maintain as compared to discharge machinery.

Accommodations for 12 passengers were provided, to transport mining ship crewmen to and from shore. Two extra stewards are needed for these riders. The extra space and hotel services would add about $1 million to U.S. standard ship costs, but less for foreign-built ships. The total costs of the modified basic ore-carrying ships are shown on Table III-4.

TABLE I-2

MANGANESE NODULES HANDLING EQUIPMENT COSTS ON SHIPS
Estimated U. S. Cost (Million Dollars)

TYPE	EQUIPMENT (Discharge Time)	Ship Size (DWT) 40,000	55,000	70,000	85,000	Foreign Cost (% USA Cost)
II	Dry Loading Conveyor	$1.8	$2.2	$2.5	$2.8	65%
III	Dry Self-Unloader Conveyor (24 hours nominal)*	5.2	6.5	7.6	8.3	70%
IV	Slurry Load Piping	0.90	1.07	1.22	1.36	55%
V	Slurry Discharge Pumps (20 hours nominal)	4.0	4.8	5.5	6.1	75%
VI	Revolving Cranes (48 hours nominal)	3.6	4.3	5.4	5.4	60%

*Not suitable for installation in bulk ship configurations. All other equipment cost estimates apply to ore, bulk, or OBO ship configurations.

American ship owners without subsidy need about 10.77% of yard cost for 25 years for capital recovery including 10% after tax profit, and 8.45% without profit. Europeans and Oriental owners need an average of 9.35% of yard cost per year for 20 years to earn a higher 20% after-tax profit, but payments are higher for the first eight to twelve years. Without profit (or taxes), average capital recovery rates of 6.41% are needed. Imported ships would need a higher 11.7% of cost capital recovery rate with conventional financing to earn 10% after tax profits.

Current Ship Operating Costs. Operating cost estimates included the components of: wages and benefits, subsistence, stores and supplies, maintenance and repair, insurance and reserves for claims, crew transportation, fuel and lube oil, overhead and administration.

Detailed estimates of the number of crew were developed for steam and diesel power ships, with and without engine room automation, without gear or with crane and other cargo handling gear. No difference in crew size by nationality was notable in the base data.

Wages and benefit costs were estimated for American and six foreign country crews, including mixed European officers and Oriental crews. For the American and Norwegian crews, labor costs are a function of ship size and horsepower, called power tonnage. For the 70,000 DWT ship with a crew of 36, the relatively lower cost of foreign labor is shown here.

Country	Labor Cost Index
U.S.A.	100%
Norwegian	58%
Italian	41%
British & Spanish	34%
Mixed foreign	25%
Taiwanese	15%

This great reduction in labor cost, an important cost component, is a major factor in the lower cost of foreign-flag ships. Subsistence (victualling) costs computed on a cost per man-day basis, are also lower for foreign crews. Stores and supplies, insurance and claims reserves, maintenance and repair, and overhead and administration cost components were all found to lie within a reasonable range of costs at any particular deadweight. Graphs depicting the cost on conventional ore-carrying ships as a function of deadweight tonnage are provided in the detailed report.

In addition, extra insurance would be needed for the passengers and added stewards on the American ship. Insurance costs would also be increased for the added value of cargo handling gear onboard.

M&R costs for the nodule handling equipment were added, at one to four percent of estimated installed equipment cost. For self-unloading and slurry discharge pumps, these costs become very expensive.

Overhead costs depend in part upon the number of ships in fleet operated, but are not very important overall.

Transportation to home of foreign crews was provided on an annual rotation. Port charges as a function of Gross Register Tonnage were estimated for U.S. Pacific coastal ports, and for ports up inland deep-draft river channels.

Fuel costs were assumed at $12.66 per barrel for Bunker C and $13.20 for diesel, and $1.75 per gallon for lubricating oil, for the appropriate consumption rate as a function of propulsion plant power. In port consumption ranged from 10% to 30% of at sea rates, depending upon the cargo handling machinery. Typical American steam ships use cheaper Bunker C fuel at a higher consumption rate than diesel ships favored by other countries' operators. Including the cost of lubri-

TABLE I-3

COMPARISON OF SHIP OPERATING COSTS
Slurry Loading Ore Carrier, 70,000 DWT
(1977 Dollars)

Nation Built	U.S.A.	European	European
Nation Registered	U.S.A.	U.S.A.	Italy
Power Plant	Steam	Diesel	Diesel
Crew	35	31	31
ANNUAL COSTS (Thousands Dollars)			
Capital Recovery	5,422	3,677	2,964
Wages & Benefits	1,470	1,390	605
Subsistence	95	95	73
Stores & Supplies	199	199	111
Insurance & Reserves	666	593	417
Maintenance & Repair	514	514	352
Overhead & Administration	126	126	63
Transportation	0	0	25
Lubricating Oil	0	67	67
Total	$8,492	$6,661	$4,677
DAILY COSTS (Dollars per day)			
Fuel at sea	8,100	6,473	6,473
Total at Sea	33,833	26,658	20,646
Total in Port	26,543	20,830	14,820
Profit, included above	3,524	2,267	2,831

cating oil, the diesel ships are less expensive to fuel and probably are equal to or lower than steam ships in other operating costs. American operators may switch from steam to diesel power for these reasons, if diesel machinery purchase and installation costs in U.S. shipyards are reasonable.

Total daily costs for the United States, Italian-crewed European ships, and imported European-built ships of 70,000 DWT size for slurry unloading are shown on Table I-3, to illustrate the typical cost estimate results. Total daily costs for Oriental ships were not calculated.

Nodule Transport Voyage Simulations: The performance and costs of the nodule carrying ship, equipped to load by either slurry or by dry conveyor, and discharge by shore equipment, were computed. Slurry handling can be slightly faster than conventional handling, as in these examples, and about 4% less expensive than dry conveyor handling. Nodule slurry transfer times at sea ranged from 22 to 33 hours from the smallest to the largest ship, and port time was within this range. Dry nodule handling may take about four hours more per cargo transfer.

Two different voyage lengths used were 1,750 and 3,800 nautical miles. These represent the typical minimum and maximum one-way trip to U.S. Pacific coastal ports from the Pacific Ocean areas of major commercial interest for manganese nodule mining, about 5° to 18° north, 110° to 180° west. Round trip voyage times were about nine days for the shorter to twenty days for the longer trip. Larger ships are slightly slower than smaller ships, and each ship is about 15% faster outbound in ballast. A deviation and current allowance of 10% of time was added to the great circle route.

The Table I-4 below summarizes the performance and costs for the service provided by one transport ship for slurry ships discharged by shore equipment. Although available for 350 days per annum, the ship may be used in nodule transport only for 330 days. Costs and performance of the mining ship nodule transfer and shore terminal discharge are expected to be the same for similar ships operated under any flag. Therefore these ship cost comparisons are expected to be valid except for small cost differences due to the choice of U.S.-built steamships versus foreign-built diesel ships.

Conclusions

The largest ship costs per ton are about three-fourths of the smallest ship costs, for any type of operation.

TABLE I-4

NODULE SHIPMENT COST COMPARISONS
(Slurry loading, shore discharge)

	Deadweight Tonnage			
	40,000	50,000	70,000	85,000
Typical Draft, Feet	36.0	38.0	41.0	42.5
Voyage				
DOMES SITE B* TO SOUTHERN CALIFORNIA				
Ship trip p.a.	28.53	26.90	25.41	24.85
Thousand tons p.a.	1,027	1,331	1,601	1,901
Ship Costs ($ per ton)				
U.S. Built & Operated	$8.65	$7.51	$6.84	$6.45
European built,U.S. Operated	6.65	5.85	5.42	5.00
European built & operated	5.22	4.56	4.18	3.83
WESTERN BOUNDARY TO ANY WEST COAST PORT				
Ship trips p.a.	14.44	13.75	13.28	12.85
Thousand tons p.a.	520	681	837	983
Ship Costs ($ per ton)				
U.S. built & operated	$17.23	$14.83	$13.21	$12.34
European built,U.S. operated	13.20	11.52	10.44	9.72
European built & operated	10.39	8.99	8.07	7.46

The European ship costs per ton are about sixty percent of U.S. ship costs, and the imported European ship net costs per ton are over three-fourths of the American ship costs.

From the base of the same size foreign ship with minimum cost, the mixed-nationality ship costs about 29% more, and the American ship nearly two-thirds more than the foreign ship. Since the ships are carrying from one-half to nearly two million tons annually, depending on the route, the annual total cost differences range from $3.5 million for the smallest ships, to $4.8 million for the largest.

The Oriental built and manned ships would be even less expensive to operate and purchase currently, and therefore would have even greater cost savings over American ships.

*Site B, at 12° North 138° West, of the Deep Ocean Mining Environmental Study (DOMES) was selected as representative of commercial nodule mining areas and is the center of three sites being examined in a major research project to assess the environmental effects of at sea mining operations.

Similar results for ore ships equipped for dry whole nodule transport are shown on Table I-5. The unit transport costs are about 5% higher for dry conventional conveyor handling than for slurry handling, when both ships are discharged by shore equipment. The European costs relative to American ship costs are in the same proportion. Larger ships are more economic than smaller ships by the same cost reduction fraction.

TABLE I-5

NODULE SHIPMENT COST COMPARISONS
(Dry Conveyor Loading, Conventional Shore Discharge)

	Deadweight Tonnage			
	40,000	55,000	70,000	85,000
Voyage				
DOMES SITE B TO SOUTHERN CALIFORNIA				
Ship trips p.a.	27.54	26.11	24.65	24.17
Thousand ton p.a.	992	1,292	1,553	1,849
Ship Costs ($ per ton)				
U.S. built & operated	$9.05	$7.83	$7.17	$6.60
European built & operated	5.45	4.74	4.35	3.97

II

SHIP CONSTRUCTION COSTS

Nodule Characteristics

Ships for carriage of manganese nodules must be designed to accept a dense commodity that utilizes only a portion of the available cargo stowage space. Nodules are reported to range in weight, as shown below, partially depending upon the amount of accompanying surface water. For ship transport, the water should be drained after loading to reduce transported weight and to assure stable cargoes in seaways.

TABLE II-1

NODULE WEIGHT-VOLUME MEASURES

	Low	Typical	High
Specific Gravity	1.1	1.45	2.0
Density, Pounds/Ft^3	69	90	125
Density, Kilograms/M^3	1.10	1.45	2.0
Stowage Factor,Ft^3/Long Ton	33	25	28
Stowage Factor, M^3/tonne	0.92	0.72	0.50

The density of nodules is intermediate between iron ore and bauxite, viz:

TABLE II-2

COMMODITY STOWAGE FACTORS

Commodity	Dry Stowage Factor Range: Cubic Meter per tonne	Cubic feet per long ton
Iron Ore Pellets	0.29-0.52	(10.3-18.8)
Manganese Ore	0.32-0.56	(11.4-20.0)
Chrome Ore	0.37-0.48	(13.2-17.2)
Manganese Nodules	0.50- .70	(18-25)
Bauxite	0.78-0.97	(28-35)
Salt	0.83	(30.)
Phosphate	0.89	(32.)
Coal	1.17-1.33	(42-48)
Raw Sugar	1.28	(46)
Crude Petroleum	1.08-1.28	(39-46)
Gasoline	1.34	(48.2)
Wheat, Corn	1.28-1.67	(46-60)

Source: W. J. Dorman, "Combination Bulk Carriers," SNAME, 1966.

Ship Types

The dense nodules may be carried in ore carrier hull types, which restrict the centerline cargo holds to a small part of the available hull space; or in bulk or ore ships which load dense ores in only some of the bulk cargo holds, leaving others empty. In either an ore ship or bulk-or-ore ship hull configuration, extra steel is needed to provide compartmentation and adequate hull strength for concentrated loads of dense ore, although all have double bottoms. Combination ships are able to carry any ore, bulk, or oil (OBO) cargo. OBOs may also be utilized for nodule transport and are flexible for carriage and pumping of other liquid cargoes. Thus, all three ship types (ore, bulk/ore, and OBO) will be considered in this analysis of ship construction prices. The basic bulk/ore or ore carrier has no cargo handling gear, although many ships are equipped with cranes and a few have self-unloading conveyors.

Nodule Handling

The nodules and fragments will probably be raised in a slurry from the ocean floor in an upward flow of sea water, by a hydraulic system, and nodules could also be transferred to and from ships as a slurry. Improved pumping efficiency will be achieved when smaller particles are produced by grinding nodules either at the sea bottom or on the mining ship. Because of the ease of handling and reduced chance of spillage of either coarse or fine particles, slurry handling on ships is considered most likely.

The nodules as raised from the seabed may be transferred at sea from the mining ship to the nodule transport ship. Conventional dry bulk handling methods utilizing belt or screw conveyors and buckets may be satisfactory to handle the nodules as raised. However, reports indicate that nodules tend to disintegrate into small particles and dust when allowed to dry and when stacked in large piles and in ship holds.

Nodules may also be dried at low temperatures to reduce weight by about 30%. However grinding and drying consumes much fuel, and produces hot, wet gases that probably cannot be used aboard ship. Also, dried nodules are dusty, and more difficult and slower in cargo handling. Therefore selection of transport of dried nodules is not considered likely by industry unless nodules are transported very much longer distances than the Pacific Ocean voyages analyzed in this report. Therefore dried nodules were not evaluated further in this analysis; only whole nodules conveying and slurry handling are examined.

Ship Characteristics

The typical dimensions of combination ships (OBOs) and other ore-carrying ships suitable for nodule transport are shown on Figure II-A and Table II-3.

A principal measure of the economic efficiency of a bulk-carrying ship is the operational capability of the ships to carry the largest deadweight possible within the limiting draft of the harbor navigation channels and ship terminal berth. Shallow draft design vessels are especially desired to maximize load capacity. A recent study by Rosenblatt (76) compared shallow draft bulk ship configurations to conventional ship designs as routinely reported by the U. S. Army, Corps of Engineers. This report and the NOAA Phase I report by Dames and Moore (77) are based upon an intermediate design configuration that is between conventional and shallow draft as shown in Figure II-B. The ship configuration selected as representative of recent combination ships. For example, at 40' (12.2 meter) salt water draft, the ship deadweights are:

Corps of Engineers-Conventional	50,000 DWT
NOAA Phase I-Dames & Moore	67,000 DWT
Rosenblatt-Shallow Draft	88,000 DWT

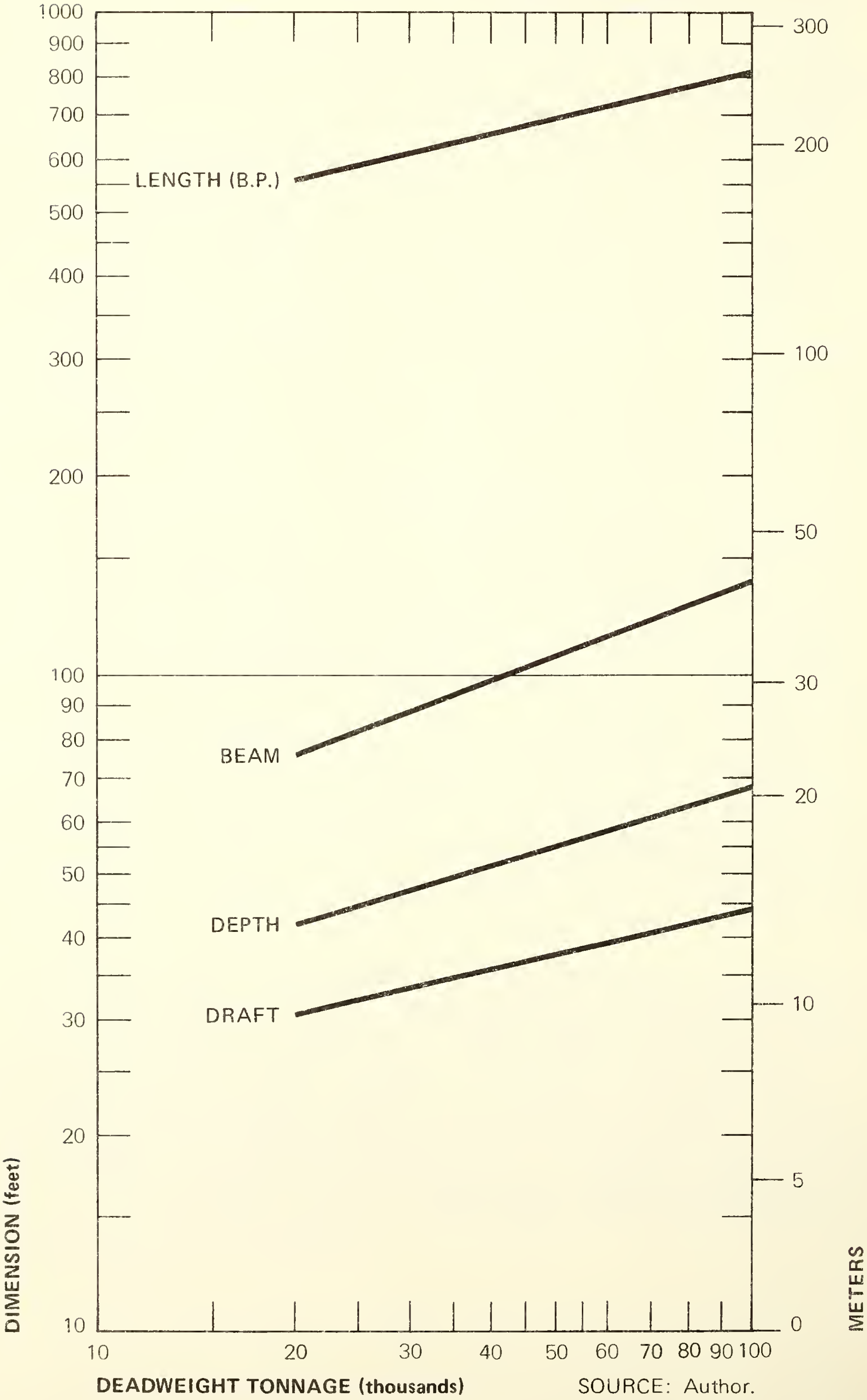
This illustrates the wide range of variation (plus or minus one-quarter of DWT) of ship designs. Costs are also subject to wide variations because of design variations.

Most American ports have 40' (12.2 m) nominal channel depth at low water in salt water. Although a small space for ship bottom clearance is needed, ship entry at mid-tidal level or high water is frequently scheduled for shorter channel lengths to secure greater water depths when transiting, and berths can be dredged deeper than the channel. Therefore loaded drafts equal to nominal depth can be accommodated.

Because of the short typical voyages to transport manganese nodules to port, the transport ships will spend much time in port and in ballast when higher speeds are secured. The speed and power of most recently-designed bulk ships have been reduced to save fuel and cost of the power plant and maintenance. Formerly most bulk ships and tankers achieved speeds when laden of 15 to 16 knots. Figure II-C depicts the approximate power requirements for various laden speeds, as a function of ship size, and for the typical ships assumed for this cost analysis.

Figure II-A

TYPICAL COMBINATION SHIP-PRINCIPAL DIMENSIONS VERSUS DEADWEIGHT TONNAGE



SOURCE: Author.

TABLE II-3

TYPICAL COMBINATION SHIP DIMENSIONS

DWT	Length B.P.		Beam		Depth		Draft S.W.	
(Long tons)	(meters)	(feet)	(meters)	(feet)	(meters)	(feet)	(meters)	(feet)
15,000	146	480	20.4	67	11.1	36.5	8.4	27.5
20,000	163	535	23.2	76	12.7	41.5	9.2	30.0
30,000	186	610	26.8	88	14.6	48.0	10.2	33.5
40,000	203	665	29.6	97	15.7	51.5	11.0	36.0
50,000	217	710	31.7	104	16.8	55.0	11.6	38.0
60,000	220	720	33.6	110	17.7	58.0	12.0	39.5
70,000	226	740	36.9	121	18.6	61.0	12.5	41.0
80,000	233	765	39.6	130	19.4	63.5	12.8	42.0
100,000	247	810	42.1	138	20.6	67.5	13.3	43.5

Notes

DWT = Deadweight tonnage in long or metric tons, the total weight capacity for fuel, supplies, crew and cargo.

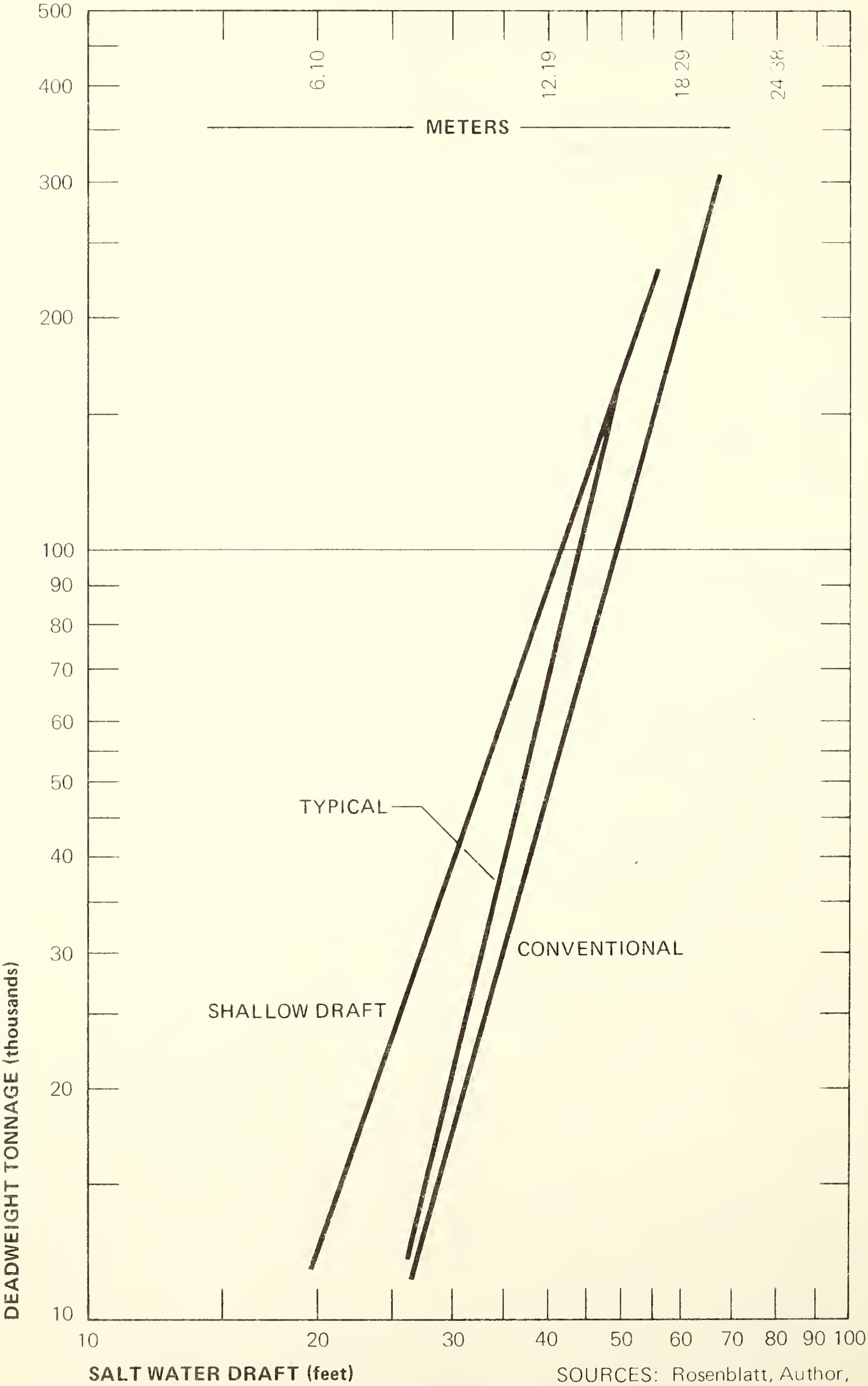
Length B.P. - Length between perpendiculars (approximately at the waterline)

S.W. = Salt water

Beam and Depth are molded dimensions inside steel plating.

Figure II-B

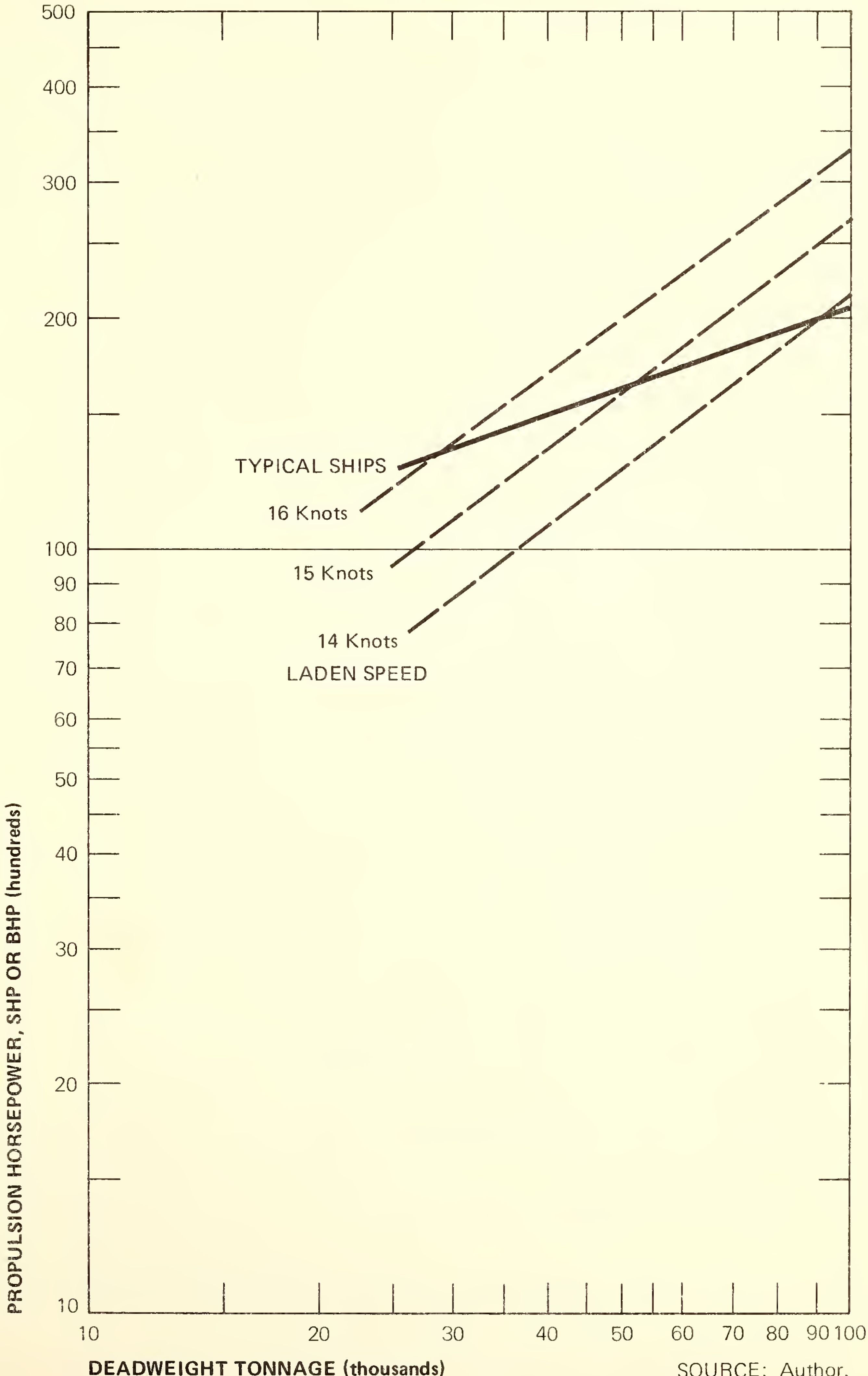
COMPARISON OF DEADWEIGHT-DRAFT RELATIONSHIPS



SOURCES: Rosenblatt, Author, Corps of Engineers.

Figure II-C

TYPICAL COMBINATION SHIPS–DEADWEIGHT TONNAGE VERSUS SPEED AND POWER



SOURCE: Author.

World Ship Construction Prices

Ship yard construction price data were accumulated for early 1977 contracting from United States, European, and Oriental building yards. These prices are not directly comparable, because the ships ordered were for 1979 delivery abroad from Oriental and European yards, or for 1980 delivery in the United States. These values are prices in local currency to be paid in installment or progress payments to the shipyard, and do not necessarily include all costs to the shipyard. For comparable delivery times, ships could be ordered later abroad but at slightly increased prices probably representing inflation. Interest during construction and changes in monetary exchange rates would alter the net dollar cost.

The American ships only are steam powered; the others are propelled by diesel engines.

As of mid-1977, shipyard costs and selling prices are not closely related in many countries. In the Orient in particular, and to a lesser extent in other countries, quoted sales prices for standard-design bulk ships are lower than their construction costs. The Oriental ship prices currently reflect extensive governmental subsidies to the yards to maintain employment and exports. Such low prices may not continue to be available for many years when nodule transport ships are ordered in the 1980s. European yards were negotiating building contracts at no-profit or lower prices, but usually at definitely higher prices than the Oriental yards.

These price differences are shown in Figure II-D depicting early 1977 yard prices for standard gearless bulk ships as a function of deadweight tonnage (DWT).* The American shipyard prices are competitive estimates including normal profit levels, for reasons discussed below.

Figure II-D shows the early 1977 shipyard prices for:

United States Construction - OBOs, self unloaders, and standard gearless ore and bulk carriers, all steam powered; and

Northern European Construction - Special-design bulk or ore ships, diesel powered,

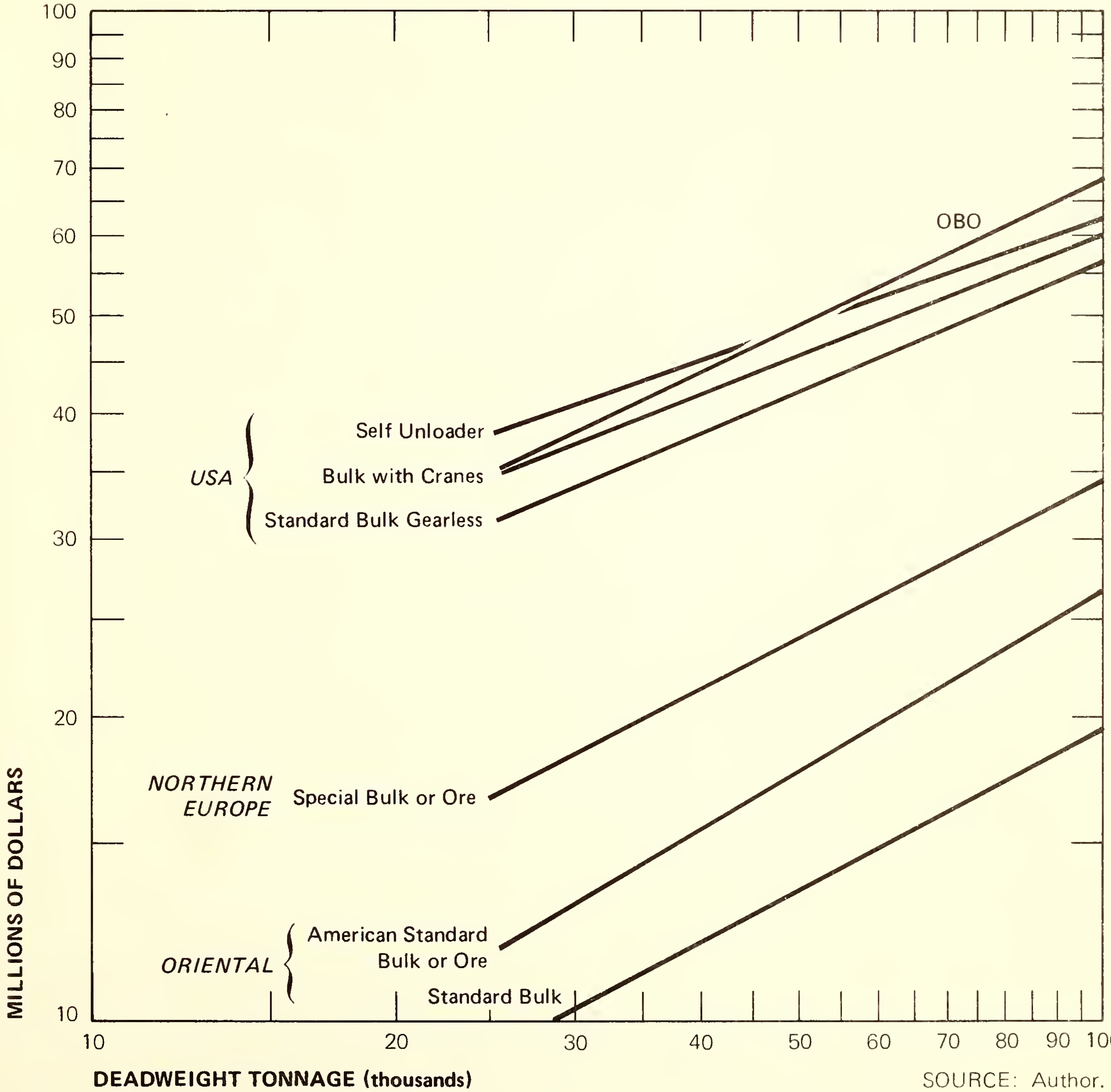
Oriental construction - American-quality bulk or ore ships, diesel powered; and

Oriental construction - Oriental-standard bulk carriers, diesel powered.

The Northern European shipyard ore-carrier ship price is most relevant to this cost comparison (versus yard price) as

Figure II-D

1977 SHIPYARD PRICES FOR BULK SHIPS BY DEADWEIGHT TONNAGE AND BUILDER



SOURCE: Author.

a base for nodule transport ships with their requirements for American-quality and special equipment. The United States-built ship costs also will be used with the cargo handling gear appropriate for the nodule transfer method.

Additional equipment will be required to transfer manganese nodules at sea by either slurry method or conveyor. Standard foreign ships will need some equipment to meet typical United States high quality standards and to meet regulations for engineering, pollution control and navigation. Hotel accommodations for transporting mining ship crewmen are also needed. These additions are described next in Section III.

The primary cause of these current abnormally low world yard prices, for conventional ships, especially in the Orient, is the depression in ship demand, especially for tankers, since the quadrupling of oil prices by the nations of the Organization of Petroleum Exporting Countries. The increased oil price has substantially diminished the demand for petroleum transport. The current oversupply of large tankers is aggravated by the construction underway of new tankers. Shipyards have permitted some cancellations of orders, but prefer to substitute other ship types for tanker orders. Most substitute orders are for bulk ships which the tanker yards can build. However, the overall world economic slowdown has also reduced demand for bulk and ore transport, and the additional bulk ships being delivered have resulted in low charter rates for bulk carriers as well as tankers, as supply exceeds demand. Therefore ship operators are not able to utilize profitably all the ships available, and the operators have reduced orders to buy new ships from the yards. Therefore the higher price of OPEC oil has resulted in low demand for new and operating bulk ships, and very low market prices for the new bulk ships and for their services on charter.

A second cause of low prices for ships built for the world market is the continuing excess capacity of shipyards to produce many more new vessels than are demanded. This excess is being aggravated by creation of new shipyards in underdeveloped countries, notably South Korea, Brasil, Spain, and in the Persian Gulf countries. To obtain orders for these yards, their governments have provided financial assistance of undisclosed amounts and form, which permit many yards to quote very low prices. This assistance may be provided through the early 1980s according to some forecasts, and result in the same abnormally low prices being quoted for manganese nodule ships ordered then. If this situation does continue for a few more years, the distinctly lower cost Oriental ship prices may then be a valid basis for comparison.

Inflation. Inflation in world shipbuilding costs has been at extremely high rates in recent years, especially compared to the mid-1960s when yard productivity improvements generally offset wage increases, while the material and equipment prices and demand for vessels held stable. Recent worldwide inflation rates on capital goods have frequently exceeded rates of price increase for consumer goods, foods, some raw materials and wages. These escalating cost trends are still continuing, and require evaluation of the shipbuilding costs quoted in this report before application without increase at future times. At the same time, the future prices charged for ships may not reflect increases in costs to the shipbuilder, unless demand for new ships increases greatly.

The Table II-4 illustrates the trend in typical world shipyard prices estimated for 70,000 DWT gearless bulk carriers. The number of all types of new ships on order and their total deadweight tonnage are also shown, to denote the softening in demand affecting the price level. After demand reached a peak in 1974 and then began to fall, ship prices fell below costs as inflation continued. This is a classic example of price elasticity on demand.

TABLE II-4

1970-77 YARD SALES PRICE, STANDARD BULK SHIP OF 70,000 DWT, GEARLESS; AND WORLD SHIP ORDERS

January 1, Year	Million Dollars Per Ship	Total Ships & DWT on Order
1977	16	2,134-78 Million DWT
1976	20	2,350-125 Million DWT
1975	25	2,646-206 Million DWT
1974	20.5	2,728-237 Million DWT
1973	15	2,227-159 Million DWT
1972	12.3	2,571-154 Million DWT
1971	11.9	2,517-141 Million DWT
1970	10.2	2,080-98 Million DWT

Note: Prices are for full cash payment at delivery. 1977 is Japanese price, others European. All ship types, bulk and tanker over 10,000 DWT, others over 1,000 GRT.

Source: Fearnley and Egers Chartering Co. Ltd., Norway

U.S. Shipbuilding Prices

The United States shipbuilding market is somewhat insulated from the above worldwide market price trend, because the principal market for U. S. built ships is the American domestic trade (cargo moving between ports of the United States and its territories) where foreign ships may not operate. This protected traffic has been increasing,

especially because of the Alaskan oil movement and the negotiated American ship share for transport of grain sold to Russia. Also, some American bulk ship companies receive subsidies for their ships engaged in foreign trade operations. Because aggregate demand for U. S. built ships and marine equipment has been at a high level for a few years, U. S. shipyards have been quoting prices which are profitable. Many United States yards have also been modernizing their facilities to lower production costs, especially for repetitive construction of larger, standard ships.

Ship prices quoted in the United States have taken a substantial increase recently, perhaps up as much as 50% within the last two years when the reports of Rosenblatt (77) on bulk ship costs are compared to these estimates. Many reasons are cited for this large increment, including additional equipment for pollution control and automation of engine room and navigation; costs of meeting governmental regulations during construction, especially for air pollution control, Occupational Safety and Health Administration regulations, and delays in approving needed yard alterations and improvements because of new Coastal Zone Management restrictions.

Capital Cost Recovery

Capital costs were the basis of the computation to determine the equivalent annual cost of vessel ownership for foreign and American ships. Factors in the analysis include depreciation, tax credits, interest and financing charges, owners' expenses, taxes, residual value and profit. Table II-5 below summarizes the significant assumptions in the computation.

The deep sea mining and mineral processing consortia of companies would have the option of either chartering (leasing) the nodule transport ships or owning them; and contracting for the operation and management of the ships, or performing these functions themselves. If the ship is owned by the consortia members or long term chartered under bareboat or time charter, the owner would expect normal earnings on the equity investment after taxes. Ownership would raise markedly the capital needed for a deep ocean mining consortia, and the consortium could evaluate the total system equity and profit separately from the vessel's profit, or include the profit on the ship investment. Both capital recovery factors, without and with return on equity investment, are shown below.

The American built ship owner is assumed to benefit from the Title XI Federally Guaranteed Ship Financing program and the deposits into a Capital Construction Fund (CCF). Net costs

would be comparable to a long term bareboat charter under a leveraged lease financing program, which are suitable for consideration by the participants in the manganese nodule mining consortia.

An imported ship of an American owner would not be eligible for Title XI financing nor use of a CCF, nor Operating Differential Subsidy. Payment of any import duty should not be required. Tax treatment would be the same for depreciation, credit, life, and salvage value as for a U.S. built ship.

TABLE II-5

CAPITAL COST RECOVERY ASSUMPTIONS

	United States	Europe	Orient
Owners Capital Expenses, % Yard Price	2%	2%	2%
Financed Amount, % Owners Cost	75%	70%	80%
Financing Expenses, % Financed Amount	2%	2%	2%
Financed Period, years	20	8	12
Mortgage Finance Interest Rate	9%	8%	8%
Ship Useful Life, years	25	20	20
Investment Tax Credit,% Owners Cost	10%	10%	10%
Depreciation Period, years	14½	12	8
Scrap Value, % Owners Cost	15%	15%	15%
Resultant Annual Capital Recovery Rate, excluding Earnings on Equity, Percent of Yard Price	8.453%	5.782%	7.038%
Tax Rate on Profits	50%	25%	25%
Equity Earnings Rate after Tax,%p.a.	10%	20%	20%
Resultant Annual Capital Recovery Rate, Percent of Yard Price	10.771%	9.408%	9.295%

The foreign ship owners would also benefit from an extensive array of shipyard export financing credits, subsidies, tax rebates and favorable tax treatments. Financing of the vessel is available at interest rates lower than in the U.S., but for a shorter term and sometimes a lesser share of the total cost. Foreign tax treatment usually permits highly accelerated depreciation, and investment credits comparable to the U.S. The foreign ship's useful life is usually shorter than American ships. The foreign owner normally has higher profit expectations than American owners. The values assumed on Table II-5 do not represent a specific country or operator situation, but are averages for a variety of seafaring nations that could provide nodule transport service under a suitable contract. (Kaplan, '74)

The results of these capital recovery computations indicate that a typical foreign ship owner must earn 9.35% of cost to meet their objective profit level. American owners need

TABLE II-6

SHIPS SELECTED FOR COST COMPARISONS
Lengths: Meters (feet)

Deadweight Tonnage	40,000	55,000	70,000	85,000
Length B.P.	203(665')	216(708')	226(740')	232(760')
Beam, Molded	29.6(97')	33.8(111')	36.9(121')	37.8(124')
Depth, Molded	15.7(51.5')	17.2(56.5')	18.6(61')	18.9(62')
Draft, Salt Water	11.0(36')	11.6(38')	12.5(41')	13.9(42.5')
Holds laden, nodules	5	6	7	8
Laden Speed, knots	15.5	14.9	14.5	14.1
Horsepower	15,000	16,600	18,000	19,400
Diesel Fuel Consumption bbl/Sea Day	405	450	490	530
Lube Consumption bbl/year	700	780	850	910
Steam Fuel Consumption (Bunker C) bbl/Sea Day	530	590	640	680

Shipyard Price - Basic Ore Carrier (Millions Dollars)				
United States	$38.0	$43.5	$48.0	$52.3
Northern Europe	21.3	25.0	28.3	31.3
Orient-American Std.	15.4	18.6	21.5	24.0
Oriental Standard	11.9	14.1	16.0	17.8

to earn more, about 10.77% of the yard price, to achieve aftertax earnings at a lower rate than the foreign owner's profit. If the ship cost were the same for both United States and foreign owners, the American owner requires on the average about 15% more for capital cost amortization, at half the rate of aftertax profit. These relatively favorable foreign investment returns are the result of low interest rates on ship mortgages, short mortgage life, very rapid depreciation, cash tax credits and low tax rates. However cash outflow is high during the first half of the ship life while mortgage payments are high.

The profit on equity represents about 2.32% of ship yard cost annually for American ships, and averages about 2.85% of the lower foreign yard price for foreign ships.

Ship Selection

The Dames and Moore (77) reports to NOAA for Phase I described at length the prospective sizes of nodule transport ships under a series of assumptions as to Pacific Ocean mining site, port location, nodule condition for transport, cargo transfer rates, annual volume to be carried, and number of transport ships used. Within the present 40' (12.2 m) draft limits usually assumed, the largest ships likely to be selected to serve U. S. Pacific Coast ports are about 70,000 DWT. Larger ships up to 100,000 DWT would be desirable if adequate water depth (about 44', 13.4 m) were available at the ship berth or offshore mooring buoy. The minimum ship size found suitable in the Dames and Moore report was about 40,000 DWT, and at 36' (11 m) draft would be able to enter many smaller U. S. Pacific coastal ports and channels.

Ships that could transit the Panama Canal, for service to U.S. Atlantic or Gulf of Mexico coastal ports, are limited in dimensions by the 110' Canal width, 900' lock length, and maximum fresh water draft of 40' during the wet season only. The largest ship able to transit fully laden is known as a Panamax ship of 55,000 usable DWT capacity, with slightly different dimensions from Table II-6. Larger ships up to about 70,000 DWT in special designs but less than full laden because of draft restrictions, may be selected for Panama Canal transit.

Therefore four ship sizes, at 40, 55, 70, and 85 thousand DWT were selected for this report as representative of the full range of nodule transport ships. The typical dimensions of these representative ships are shown on Table II-6, with the United States, European and Oriental shipyard prices for their standard ore carrier ship products, which may be modified for nodule transport.

III

EQUIPMENT FOR NODULE TRANSPORT SHIPS

The standard ore, bulk/ore, or OBO ship of typical design could probably not be used without modification for transport of manganese nodules. The modifications include improvements to some foreign ships to meet American standards for pollution control and navigation, and to reduce operating costs, equipment for handling nodules at sea or in port, and passenger accommodations for crew men of the mining ship. These equipments are described below, with an estimate of cost provided for their installation aboard conventional ships in ocean commerce described in Section II.

EQUIPMENT FOR COMPARABLE STANDARD SHIPS

The wide differences in costs reported between American, European and Oriental ships can be narrowed slightly by consideration of differences in specifications of the vessels' designs.

United States merchant ships must meet requirements of the Coast Guard, Public Health Service, Environmental Protection Agency, Maritime Administration, American Bureau of Shipping, and occasionally the Corps of Engineers, Occupational Safety and Health Administration, Federal Communication Commission, and numerous equivalent state and local agencies for air, water and noise pollution control, navigation, and liability. In addition, labor unions of shipboard and shoreside employees are able to demand minimal standards of quality for vessel operations under United States flag. In addition, experienced American operators chose to install superior components and materials in their vessels flying any flag, because future savings in maintenance and repair, reduced fuel consumption, reduced shipboard labor, increased reliability of operation and safety, and other reductions in direct operating costs will be worth more than the initial cost of the improvements. To separate the specific cause for the higher standard of each item in United States ships is not necessary. The typical first-class design and construction of United States subsidized ships has been taken for this analysis as the American "standard."

United States, Scandanavian, and many European ship operators all typically require these same highest standards for their vessels, whether under Liberian, Oriental, or national flags; so this description should not be construed as being uniquely for American-flag ships. In some respects, Scandanavian and other ship operators have higher standards. For example, many Scandanavian cargo ships have swimming

pools, saunas, closed-circuit television and movies, load computers, and complete engine room automation for unattended operation. These features are desirable to attract competent crew men for extended shipboard assignments. Because of the American unions' six-month maximum on-board time policies for crew rotation, few United States ships have such features.

Table III-1 lists a number of equipment units and improvements expected to be provided on U.S. nodule transport ships, which may not be installed on comparable but lowest-cost foreign ships. While not all items listed would be lacking on lowest-cost foreign ships, many equipments listed would be of higher quality than typically provided. The most expensive improvements are most difficult to pinpoint. Examples of upgrading expenses are superior epoxy coatings which sometimes permit slightly thinner steel structure; automatic hatch cover opening, closing and sealing; improved shape of cargo holds to facilitate cargo handling; engine room automation; and superior accommodations for the crew.

Few items with relatively low cost are required for nodule transporters by United States regulatory authorities exceeding the requirements of international organizations or standards. Recent regulatory proposals in the area of navigation equipment and supplies, fire protection, and oil, cargo and air pollution from machinery exhausts and sewage are assumed in this analysis to be adopted and required of nodule transport ships. The manganese nodules from the sea are assumed to be a non-polluting substance and therefore not to require special precautions onboard ship needed for stowage and handling hazardous chemicals or oils.

Most of the items on Table III-1 are voluntarily installed by the owners, especially the Scandanavian and Europeans, as noted above. And not all items are needed additions to every "cheap" ship, because even the lowest-cost ship must still meet minimal classification requirements and be maintained in class. Also, little additional equipment can be installed to improve diesel engine performance, and most foreign bulk ships are diesel powered.

Designs of many foreign and American ships were reviewed to identify the items on Table III-1, and further estimating was required to produce the costs of Table III-2. Assumptions as to equipment additions for typical Oriental and European design ships were based upon the design reviews.

Table III-3 lumps several items together for the smaller cost groups. These groups (as well as the larger cost items mentioned earlier) have been the subject of economic analyses by international and regulatory organizations, as to their benefit-cost ratios or rate of return on investment.

TABLE III-1

ADDITIONAL EXPECTED EQUIPMENT TO BE PROVIDED

ON U. S. NODULE TRANSPORT SHIPS

(Compared to Lowest-Cost Foreign Ships)

NAVIGATION

Bridge-to-Bridge VHF radio telephone
Collision-avoidance radar system
Direct speed indicator (log) and position recorder
Loran C and Omega position fixing
Continuous-Recording depth sounder
Vessel rate of swing indicator
Interior communications system testing
Stability computations and directions
Emergency position indicating beacons
Automatic anchor release
Constant tension winches
Hydraulically operated hatch covers
Facsimile (weather chart) printer

STRUCTURE

Two-cargo hold standard of subdivision
One-engine room standard of subdivision
Self trimming and hopper shaped cargo holds
Easy access to pumprooms
Cofferdams and separation of fuel spaces
Engine room fixed CO_2 systems
Epoxy coating of hull and holds
Details to reduce hull stress concentrations
Design to minimize cargo shifting
Bulbous Bow
Cross-flooding outbaord compartments
Flume stabilizer
Impressed current hull protection (vice anodes)

OIL TANKS

Remote liquid level indicators
Inert gas system
Tank vent vapor recovery system
Oil-content water meters and automatic pump stop
On-deck collectors for spilled oil
Remote quick-closing shutdown of cargo oil pumps
Overflow alarms
Low steam temperature piping
Tank ventilation equipment
Reserve heater and condensate pumps, hi-level alarm and trip

Table III-1 - Concluded

MACHINERY

STEAM SHIPS

One-man engine room automation
Automatic low-excess air oil firing (combustion control)
In-port clean fuel firing
Increased astern power
Air pumps (vice ejector)
High-pressure feed water heaters
Condensate filter systems
Feedwater purification systems
Auxiliary/port boiler
Steam traps

DIESEL SHIPS

Unmanned-nights-engine room automation
Separate lube oil cooler
Inlet and exhaust silencers
Separate scavenge air compressor
Fuel oil sulfur and vanadium treatment
Fresh water engine cooling.

BOTH STEAM AND DIESEL SHIPS

Fixed CO_2 systems
Lower propeller rpm, more efficient blade design
Oil-lubricated stern bearings
Smoke intensity alarms and monitors
Exhaust gas scrubbers
Noise-reduction in engine rooms
Two separate main fire pump systems
Shore line connection for all bilge and ballast systems
Bow thruster
Sewage treatment system
Condensate-cooled distillers
Sanitary holding tanks and shore transfer system
Multiple diesel generators with extra capacity
Higher powered or duplicate emergency generator
Extraordinary system testing and control through automation
Automatic testing of engine automation and controls
Cooling water pump (vice scoop)
Spare propeller, tailshaft, and parts

ACCOMMODATIONS AND HOTEL

Garbage grinder and incinerator
Fixed fire protection system
Non-combustible furniture and fittings
Long-lasting deck coverings, hardware, plumbing
Noise and vibration insulation
Water washing of ventilation intakes
One man rooms with private head
Stores crane and elevator
Air conditioners

However the basic foreign, Oriental or European ships are not a singular design, but a loosely-defined vessel, and this cost estimate must relate to this non-specific base case.

The costs sources for these additions included Coast Guard analyses, the Maritime Administration, data reported in a large number of technical publications, from the United Kingdom and Scandanavia in particular, and vendor data and analyses.

On Figure II-D, the graph shows the difference in price between Oriental standard and U.S. standard bulk/ore ships built in the Orient, from hard data for the two versions of the same ship. The difference between these two yard prices, \$3.5 to 6.2 million, is almost equal to the total additional cost estimated on Table III-2. The European ships' costs would be increased \$1.2 to 2.2 million in the range of ship sizes of interest, and minimally-equipped Oriental ships would be increased three to six million dollars over their base costs to meet the higher standards. The ship improvement total costs are probably accurate within ±20%, however the individual cost items on Table III-2 may be easily ±50% in error. The foreign steam ships will eventually be priced higher than those diesel propelled, if built to the highest standards. The basic foreign ship cost data (Figure II-D) was for diesel ships, and for the remainder of this report all foreign ships will be assumed as diesel-powered.

NODULE HANDLING EQUIPMENT

The manganese nodules and fragments may be handled either in a drip-dry form by conventional dry bulk conveying equipment, or wet by the same method they are as raised from the ocean bottom, piped in a water slurry. Both dry conveying and slurry methods of handling equipment may be installed on board the ore-carrying ship for loading nodules at sea, or for discharging in port, or for both loading and discharging. Five different ship handling equipment sets have been identified for installation cost estimating; for service as shown below.

	Nodule Handling Form	
	Whole	Slurry
Ship Equipment	SHIP EQUIPMENT	
Standard Gearless - Type I	Not usable	Not usable
Ship load at bow only	II, conveyor	IV, piping
Ship discharge only	VI, cranes	Not used
Ship load and discharge	III, self unloader	V, slurry pumps

TABLE III-2

COST ESTIMATES FOR ADDITIONAL EQUIPMENT EXPECTED ON FOREIGN SHIPS

(Thousand Dollars)

Ore Carrier	Deadweight Tonnage 40,000	55,000	70,000	85,000
NAVIGATION				
Coast Guard Proposals	$ 130	$ 135	$ 140	$ 145
Stability Computations*	10	13	16	20
Constant-tension winches*	100	130	165	200
Hydraulic hatch covers	200	240	275	300
STRUCTURE				
Coatings+	1,000	1,250	1,500	1,700
Flume Stabilizer*	100	120	140	160
Hopper Holds*	300	340	370	500
CO_2 Systems*	20	30	35	40
Miscellaneous	10	20	30	40
OIL TANKS				
Coast Guard Proposals	40	45	50	55
MACHINERY				
All Steamship Items+	350	365	385	400
All Diesel Items*	100	110	120	130
Both Steam and Diesel+	100	200	300	400
Automation+	600	620	640	660
Sewage Systems*	250	300	350	400
Generators+	300	350	400	450
HOTEL				
Fire Protection Items+	50	60	70	80
Quality Appointments*	200	220	240	260
Miscellaneous Equipment	100	120	140	160
Total, Oriental: Steam	$3,400	$4,500	$5,300	$5,800
Diesel	3,200	4,200	5,000	5,700
Total, European: Steam	1,350	1,850	2,150	2,400
Diesel	1,200	1,700	1,950	2,200

Notes: Oriental Ships require all of the equipment and at costs estimated on the table.
Where * is shown, European Ships would not require this expenditure.
Where + is shown, European Ships would require half this amount.
Where no symbol is shown, European Ships would incur the full cost shown.

The following paragraphs describe briefly the cargo handling equipment provided on each ship type.

I Gearless Ship

The basic ore carrying ships are described in Section II of this report. The typical equipment and costs estimates for equipment needed on foreign ships to achieve equivalence with American ships were described in the first part of this section. These high quality standard but gearless-ore-carrying ships are not equipped to receive nodules at sea nor unload nodules by any method but could handle mining ship supplies in small amounts using a stores crane.

Fuel oil for the mining ships could also be carried on the standard transporter ships, since less than 2,000 long tons per voyage would be needed. This amount represents the lower limit for application of IMCO rules for tanker ships, and therefore any prospective problem from application of tanker rules could be avoided. If all cargo handling machinery could be located on the mining ship and at the terminal, high standard, gearless ore-carrying ships would be widely available and could be used. However even receiving the nodule cargo aboard at sea probably cannot be accomplished safely and efficiently without some ship gear.

II Whole Dry Nodule Ship Loading Conveyor

The whole dry nodules and fragments may be offloaded from the mining ship to the transporter by an enclosed belt conveyor, fed from the nodule storage hopper, or fed almost directly from the underwater mining system after dewatering. The conveyor could extend from one side of the mining ship and load directly into the nodule transport ship cargo holds in turn. This would require precise navigation or some mechanism as part of the conveyor to compensate for relative ship motions and to direct the stream of nodules into the proper hatch openings. A more likely alternative is to extend a conveyor aft from the mining ship to dump the nodules into a hopper on the forecastle deck of the tranport ships. From there, a simple loading conveyor on the transporter could rapidly distribute the nodules into cargo hatches while underway. This aft arrangement has been assumed for costing purposes, although alongside or aft transfer would have similar equipment and costs. These systems were used by the U.S. Navy for passing coal in the early 1900s.

III Whole Dry Nodule Discharge, Self-Unloading Conveyor

A self-unloader conveyor and boom system may be installed onboard the transport ship, as is common on Great Lakes coal, limestone and iron ore carriers. A conveyor under the

cargo holds discharges the dry nodules into a spout conveyor which swings over the side to discharge ashore. This self-unloading system can achieve relatively high transfer rates, sufficient to discharge the ship in one day if rated speed could be maintained. However, most conveyor systems are slower when cleaning the hold at the end of discharge, and actual average transfer rates are one-half to three-fourths of nominal speed. The average rate depends upon the ease of handling the cargo and the extent of cargo removal; and the ship size. Because the nodules are almost dry and reasonably dense, cargo transfer rates of 1,500 tonnes per hour (for 40,000 DWT ships) to 4,000 tonnes per hour (at 100,000 DWT) can be achieved by shipboard equipment installations.

The conveyor above deck could possibly be arranged to receive nodules from the mining ship and fill the cargo holds. The details of equipment location and reversibility of the above-deck conveyors permit several alternatives for loading from the mining ship. In all cases, the weight of the self-unloading gear would reduce the deadweight tonnage of the nodule transporters, and the self-unloader gear is the most expensive installation.

IV Slurry Loading Piping

For transferring nodules at sea in a slurry to the transport ship, receiving and distribution piping would be installed on the weather deck of the ore transporter. The slurry loading system is the least expensive nodule loading system, and probably the safest since only the slurry hose need connect the two ships while underway, either alongside or astern. The transfer rate could be quite high, limited only by the slurry pumping capacity on the mining ship. A boom to lift the hose aboard, and pumps for the decanting and dewatering of the cargo hold would be needed on the ore carrier.

An ore ship with only slurry loading piping equipment must be discharged by shoreside machinery. Shore slurry equipment is expected to be the lease expensive method to achieve fast port turnaround time. A shore crane of 15 to 25 tons capacity for each unit would be provided to hold each slurry discharge unit. Each pump unit would have a 450 to 900 long tons per hour transfer rate. Five to eight sets, one per loaded hatch, would be needed, at a cost not estimated. Shoreside slurry equipment maintenance would be easier, and utilization higher for shore-mounted slurry discharge than for similar onboard ship equipment, Type V.

V Slurry Loading and Discharge Pumps

Cargo sumps, water jets and pumps, slurry pumps and overboard discharge piping could all be installed on board any bulk ship to discharge a nodule sea water slurry. The slurry systems sized for this nodule handling application assumed 20 hours for ship discharge at full (nominal) pumping rate. However the starting sequence and reduced effectiveness when each hold is nearly empty will increase the total time for discharging to one day.

The shipboard slurry discharge system is more expensive to install than onboard cranes, less expensive than a dry conveyor self-unloader. But slurry handling is faster then either method. The maintenance of this ship slurry pump equipment is expensive since it is located in the bottom of the hull, and is estimated at 4% annually of the installed cost. Most of the repairs would be performed in port, thus delaying the ship. Although offshore discharging at a monomooring buoy is possible with this shipboard slurry pump installation, berths at a pier are preferred to expedite ship operations.

A viable alternative to shipboard slurry discharge equipment is to provide shore-mounted machinery described under IV above.

If tailings from processing of manganese nodules are permitted to be carried by the transport ship for disposal at sea, then onboard slurry pumping systems are essential. The relative costs of waste disposal methods, both on shore and at sea are being evaluated by EIC Corp. for NOAA. That report utilizes the data presented here for the transport ship to carry nodules ashore and tailings to sea for disposal.

VI Revolving Cranes

Whole nodules may also be transported by bulk/ore ships with conventional gear, revolving cranes of 15 to 30 tons capacity at each hold. These ships are generally available at the prices shown on Table III-3, especially in the smaller sizes. However cranes equipped with suitable clamshell buckets are slow to discharge nodules, normally about half as fast as self-unloading conveyors. But cranes cost slightly more than half as much for the installation as compared to the self-unloader. For frequent short trips to transport nodules, faster handling is desired to optimize sea time and port time. Although the cranes could also load nodules from the mining ship, the method and arrangement would probably be dangerous because of risk of collision while navigating alongside in the seaway for extended times, and the motion of the buckets caused by the sea. As a positive benefit,

cranes can also transfer loads of supplies, people, and wastes to and from the mining ship, and can dispose of solid waste tailings over the side in normal weather.

HANDLING EQUIPMENT SUMMARY

Table III-3 summarizes United States costs estimated for the added equipment on the five types of nodule handling installations for four different size ore, or bulk/ore ships. However System III, the self-unloading conveyor for dry handling, cannot be reasonably installed on conventional design bulk ships with alternate holds for ores, because the wide, flat tanktops are installed instead of hopper-shaped holds needed for nodule stowage and conveyor feeding. All types of handling equipment are sized and prices are estimated to achieve 100% of deadweight tonnage cargo discharged in the port time shown on the table. This rate of performance is not always provided normally on existing vessels of the type, which normally sail longer voyages and handle fewer shipments. The foreign cost of equipment installation is estimatable through the fraction of U. S. cost anticipated for each system. More sophisticated, unusual machinery installations cost relatively more overseas than simple installations such as slurry loading piping for example.

TABLE III-3

MANGANESE NODULES HANDLING EQUIPMENT COSTS ON SHIPS
Estimated U. S. Cost (Million Dollars)

TYPE	EQUIPMENT (Discharge Time)	Ship Size (DWT) 40,000	55,000	77,000	85,000	Foreign Cost (% USA Cost)
II	Dry Loading Conveyor	$1.8	$2.2	$2.5	$2.8	65%
III	Dry Self-Unloader Conveyor (24 hours nominal)*	5.2	6.5	7.6	8.3	70%
IV	Slurry Load Piping	0.90	1.07	1.22	1.36	55%
V	Slurry Discharge Pumps (20 hours nominal)	4.0	4.8	5.5	6.1	75%
VI	Revolving Cranes (48 hours nominal)	3.6	4.3	4.9	5.4	60%

*Not suitable for installation in bulk ship configuration. All other equipment cost estimates apply to ore, bulk, or OBO ship configurations.

PASSENGER ACCOMMODATIONS

The consortia operators of manganese nodule mining ships will attempt to maximize ship sea time and production. Thus the crew of the mining ship will probably be rotated ashore and be carried on the nodule transport ships.

The distance from the probable mining sites to nearest land and airports will probably be in excess of 600 miles, too far for helicopters or high-speed crew boats to provide a passenger service. Hawaii, Revilla Gigedo, Clipperton, or Christmas islands could serve as a personnel transfer point if mining operations are located close enough. However the current areas of principal nodule interest are not near them.

To avoid any problem with international and Coast Guard regulations, a limit of twelve mining ship crewmen may be considered as passengers. To service this added passenger crew, at least two stewards would be required, increasing the accommodations required by 14 total. The additional accommodation would represent a significant increase over the base crew of 26 to 37 men expected for the nodule transport ship, therefore additional messing and living spaces must be provided aboard the transport ship.

Based upon the deck area and type of accommodations likely to be provided, the extra cost of the passenger spaces is estimated at one million dollars for U.S. built ships. For the European built ships, the added cost would be about 70% of American cost, and 50% in the Orient.

TOTAL NODULE TRANSPORT SHIP YARD COSTS

The sums of the conventional ship costs, added costs to meet the highest design standards, nodule handling equipment and passenger accommodations costs are shown on Table III-4 for American, European, and Oriental construction of each of six bulk/ore ship types. All the base ships are combination bulk/ore ships, with cargo handling gear additions (as described before): load conveyor, self-unloader, slurry loading, slurry load and discharge, and crane equipped for dry bulk handling. Four ship sizes of 40, 55, 70 and 85 thousand deadweight tons have been selected to cover the likely range of nodule transport ship sizes. The U. S. ships are steam boiler and turbine powered, and foreign ships are diesel propelled; all are automated.

The United States flag ships cost about $42 million for the smallest of the sizes (40,000 DWT) to about $60 million for the largest (85,000 DWT). The comparable European ship costs are estimated at $25 to $37 million, respectively,

TABLE III-4

Manganese Nodule Transport Ship Costs
(Million Dollars, 1977)

Ship Type (with 12 passengers)	Deadweight Tonnage (DWT) 40,000	55,000	70,000	85,000
UNITED STATES Steam, Automated				
I Standard Bulk/Ore, Gearless	$ 39.0	$ 44.5	$ 49.0	$ 54.3
II Standard Bulk/Ore, Load Conveyor	40.8	44.5	51.5	57.1
III Bulk/Ore, Self Unloader	44.2	51.8	56.6	62.6
IV Bulk/Ore, Slurry Loading	39.9	45.6	50.2	55.7
V Bulk/Ore, Slurry Load & Discharge	43.9	50.4	55.7	61.8
VI Bulk/Ore, Crane Load & Discharge	42.6	48.8	53.9	59.7
EUROPEAN Diesel, Automated, U.S. Standard				
I Standard Bulk/Ore, Gearless	23.2	27.4	31.0	34.2
II Bulk/Ore, Load Conveyor	24.4	28.8	32.6	36.0
III Bulk/Ore, Self Unloader	26.8	32.0	36.3	40.0
IV Bulk/Ore, Slurry Loading	23.7	28.0	31.7	34.0
V Bulk/Ore, Slurry Load & Discharge	26.7	31.6	35.8	39.6
VI Bulk/Ore, Crane Load & Discharge	25.4	30.0	34.0	37.4
ORIENTAL, Diesel, Automated, U.S. Standard				
I Standard Bulk/Ore Gearless	15.9	19.1	22.0	24.5
II Bulk/Ore, Load Conveyor	17.1	20.5	23.8	26.3
III Bulk/Ore, Self Unloader	19.5	23.7	27.3	30.3
IV Bulk/Ore, Slurry Loading	16.4	19.7	22.8	25.3
V Bulk/Ore, Slurry Load & Discharge	19.4	23.3	26.8	29.9
VI Bulk/Ore, Crane Load & Discharge	18.1	21.7	25.0	27.7

less than two-thirds of U. S. building costs. The comparable Oriental ships cost estimates were about \$18 to \$27 million, less than half of American costs. These differences are most significant, as the capital cost recovery is estimated to be the largest single element of total transport costs, at approximately 40% of the total cost for U. S. flag ships.

IV

OPERATING COSTS

Nodule transportation ship operating costs were estimated from data on operating costs of bulk and ore-carrying ships in commercial service. The range of ship sizes and powers in the data were, as previously described, greater than reported here. Crew data from several different countries were examined to ascertain current manning and early 1977 cost levels.

The operating cost categories include:

- Crew Wages and Benefits
- Subsistence (Victualling)
- Stores, Supplies and Equipment
- Insurance and Reserves
- Maintenance and Repair
- Overhead and Administration (G&A)
- Transportation
- Lubricating Oil
- Fuel Oil
- Port Costs

To these costs were added the costs for operating any special pollution control, navigation, accommodation or nodule handling equipment, as described under each cost category.

Crew Size

The cost of the crew is often the third largest component of ship total daily costs, after capital and fuel costs. An analysis of manning schedules reported for many bulk ships in single cargo, port-to-port, irregular charter (tramp) service indicated the number of crew depends principally on the ship size, type of power plant and degree of automation, and cargo handling gear on the ship. Table IV-1 summarizes the typical crew sizes for single screw steam and diesel-propelled ships, with and without crane cargo gear, in the 25 to 100 thousand deadweight tonnage range.

No difference was ascertainable between the number of men on U.S. and on foreign ships of the same description. Generally, the most recent bulk ships are diesel-propelled, have automated engine rooms for one-man or unattended operations, and had no cargo handling equipment; all these factors reduce the crew size. On the other hand, large and old steam ships, especially those with self-unloader conveyors, require more crew, in extreme cases double the minimum number of crew on modern, simple ships.

TABLE IV-1

BULK SHIP MANNING SCHEDULES
(Number of Men in Crew)

DWT	Power: Automation: Gear:	Diesel Auto NoGear	Steam Auto No Gear	Diesel Auto ChGear	Steam No Auto No gear	Steam Auto ChGear	Steam No Auto CHGear
25,000		25	28	29	34	32	38
40,000		26	30	30	36	34	40
55,000		27	31	31	37	35	41
70,000		28	32	32	38	36	42
85,000		29	33	33	39	36	42
100,000		30	34	34	40	37	43

The Table IV-2 below summarizes the basic crew requirements for the selected bulk ships by size, propulsion machinery and type of cargo handling gear, plus two stewards for the passengers, for all flags of operation.

TABLE IV-2

TOTAL NUMBER CREW

Bulk/Ore Ship, Automated		Deadweight Tonnage (DWT)			
Ship Type	Power Plant	40,000	55,000	70,000	85,000
I Standard Gearless	Diesel	28	29	30	31
	Steam	32	33	34	35
II Load Conveyor	Diesel	30	31	32	33
	Steam	34	35	36	37
III Self-Unloader	Diesel	35	36	37	38
	Steam	39	40	41	42
IV Slurry Unloading	Diesel	29	30	31	32
	Steam	33	34	35	36
V Slurry Load	Diesel	34	35	36	37
& Discharge	Steam	38	39	40	41
VI Cranes	Diesel	32	33	34	35
(Standard Gear)	Steam	36	37	38	39

The principal need arises at sea for additional crew for operating cargo handling equipment, not in U. S. ports where longshoremen, stevedores, or chemical workers operate the equipment. Therefore all nodule ships with handling gear require about the same number of ship crewmen. However the Type II and IV ship crews were reduced and the crews increased for ship types V and VI, and especially for type III, the self-unloader.

Wages and Benefits

The wages, vacations, benefits and taxes paid for the crew from each country are shown in Figure IV-A. These estimates reflect the largest differences by nationality and crew size; additional increments in wages are a function of ship size and power (measured by horsepower-tons in union agreements). Deck and engineering officers are paid more for service on larger and more powerful ships; Figure IV-A attempts to illustrate this relationship. The average wages per crew man decrease for larger crews on any size ships, as added men are employed at lower skills.

As shown on the table below, Norwegian wages are 62% of U.S crew costs, Italian crew costs (considered typical of the industry) are less than half of American, and the cost of mixed European officers and Oriental crews, is less than one-third of all American manning, while all-Oriental manning is one-fifth of U. S. labor costs. This labor cost difference is one of the largest between United States and foreign operating costs.

TABLE IV-3

SAMPLE SHIP MANNING COSTS BY COUNTRY
Basic Crew Cost per Year (Thousand Dollars)

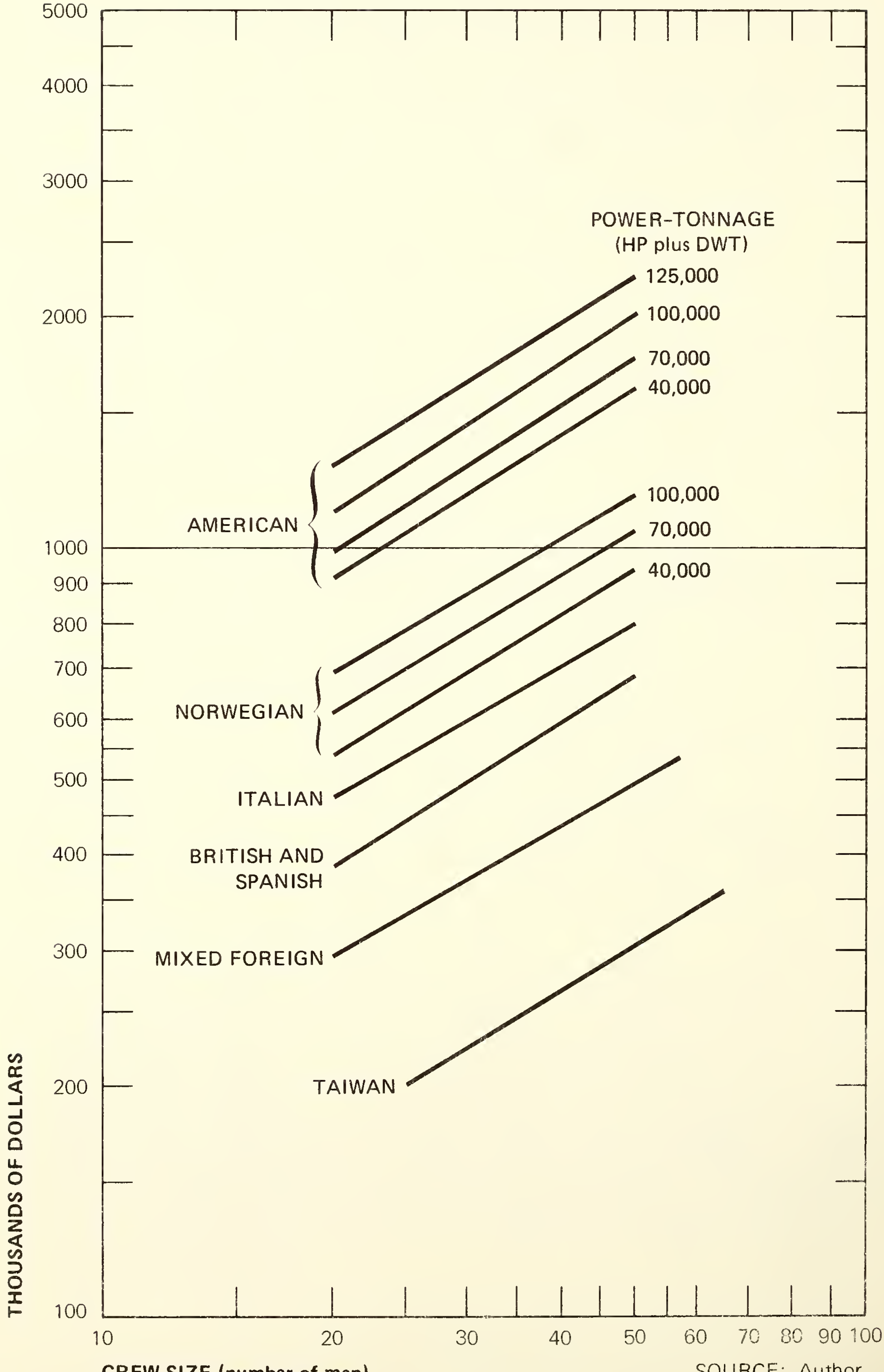
DWT	40,000		55,000		70,000		85,000	
DWT + HP	55,000		71,000		88,000		105,000	
Crew Size	26	34	27	35	28	36	29	36
Country								
American	1,100	1,310	1,190	1,400	1,380	1,620	1,400	1,620
Norwegian	660	680	730	850	800	940	890	1,000
Italian	550	640	560	650	570	660	580	660
British/Spanish	450	530	460	540	470	550	480	560
Mixed Foreign	340	400	350	405	350	405	360	410
Taiwanese	200	240	210	245	210	245	220	250

Subsistence:

Food and galley supplies are a relatively small cost item. The standard of quality and the menu served influences the cost for each nationality served, as shown on Table IV-4 below in cost per man-day served. Many ships, including nodule transporters, will provide meal service in port for company officials, government representatives, amd servicing managers, in addition to the crew. The nodule ships may be carrying up to 12 men from the mining ship crew as passengers, and therefore increase subsistence expenditures.

Figure IV-A

TOTAL ANNUAL WAGES AND BENEFITS BY COUNTRY



SOURCE: Author.

TABLE IV-4

SUBSISTENCE COSTS

Nationality	Subsistence Cost (Dollars per man-day)
American	$ 5.50
Norwegian	4.50
Italian & British	4.00
Oriental	3.50

These costs assume Pacific Coast location of purchase of all foods at the port of call, which tends to decrease the spread in victualling costs.

Stores, Supplies and Equipment

Materials needed for daily operation of the vessel and crew often border on maintenance and subsistence categories, and result in some inconsistencies in the amounts reported. Figure IV-B illustrates the range of stores and supplies costs reported for both American and foreign bulk ships.

The foreign ship cost data was for ships not equipped with cargo handling gear, while some of the American data included minimal equipment on board. The high side of the foreign range will be utilized for this cost analysis since all materials must be delivered to the ship at a U. S. Pacific Coast port, additional equipment will be installed, and operated to high standards. The best estimate line on Figure IV-B will be assumed for American-flag ships.

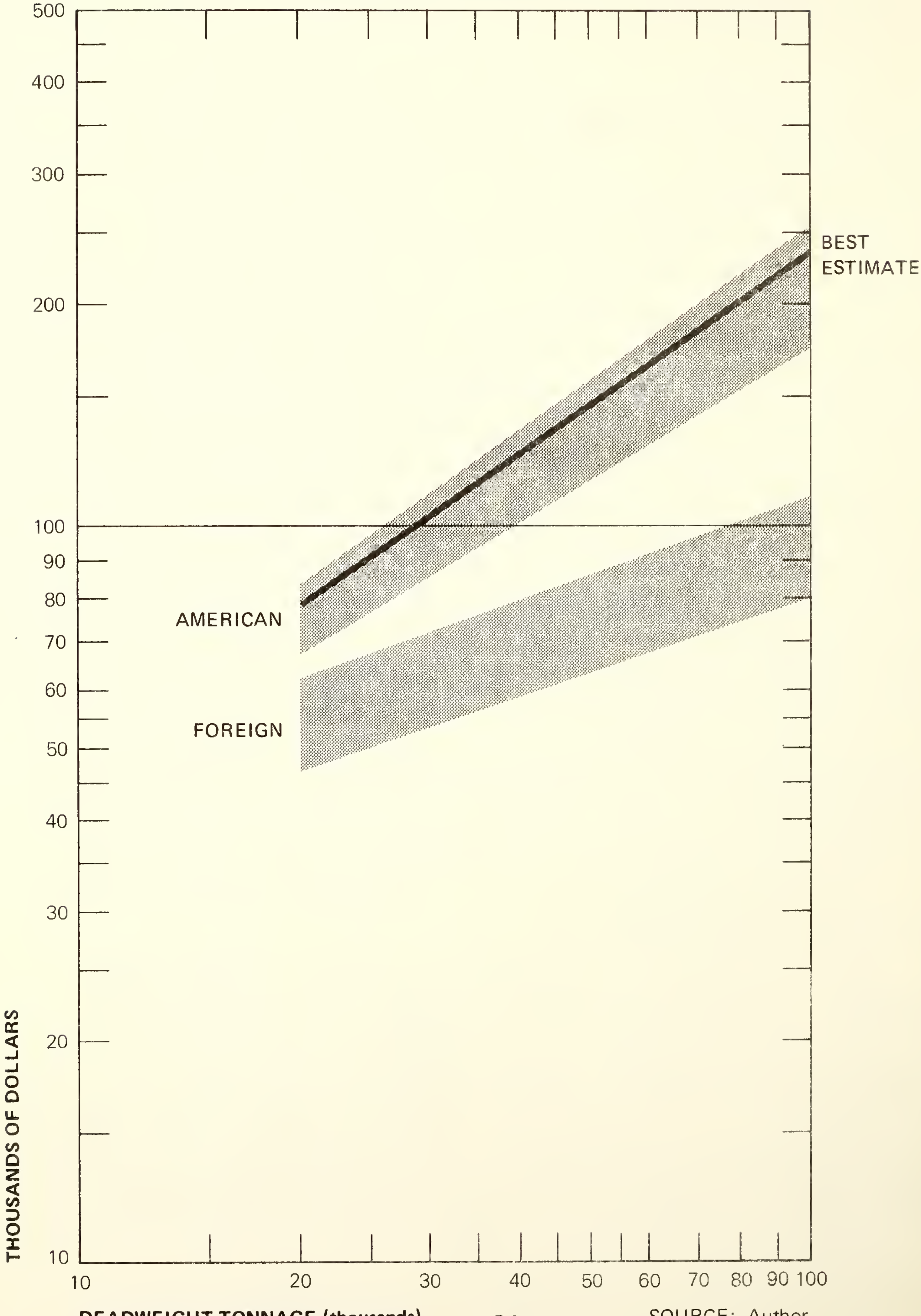
The additional stores and supplies expenses for nodule handling equipment are estimated at $5,000 to $10,000 annually for the smallest to the largest ships. This expense also increases for large crews and for regular carriage of the mining ship crew, and is estimated to cost $6,500 for all U.S. ships and 80% of that for all foreign ships.

Insurance and Reserves

The values on Figure IV-C reflect estimates of total 1977 premiums for Hull and Machinery, Protection and Indemnity, War Risk, Second Seamans, and Shipowners Legal Liability (for deviations) insurances for standard American and foreign gearless ships. Also included in the costs are reserves for claims under the deductibles under the various coverages. Cargo interests' insurance is not included, nor is loss of earnings insurance for the ship owner. The costs illustrated by a line actually fall in a wide band, with differences in insurance premiums and deductibles largely

Figure IV-B

TOTAL ANNUAL STORES AND SUPPLIES COST



SOURCE: Author.

established by the ship operator's loss experience.

Unless the government rules are revised, tanker pollution liability insurance should not be required for nodule transport ships carrying small amounts of fuel (less than 2000 tonnes) to the mining ship.

In general, this category for insurance of American ships is at least 50% more expensive than foreign insurance costs, principally because of the number and amount of claims of stevedores and seamen, the larger crew size, and the higher ship value.

For the additional passengers and crew, the U. S. cost was increased by only $11,000.

The American transport ship cost for a safe, high quality operator with a fleet of many ships and a good loss record may be roughly estimated by a formula where:

Total Insurance Cost=$151,000+$4.50(DWT)+0.4% (ship cost)

Insurance costs tend to decrease as the value of the vessel decreases, to some extent offsetting the increase in maintenance and repair costs as the ships become older.

Maintenance and Repair

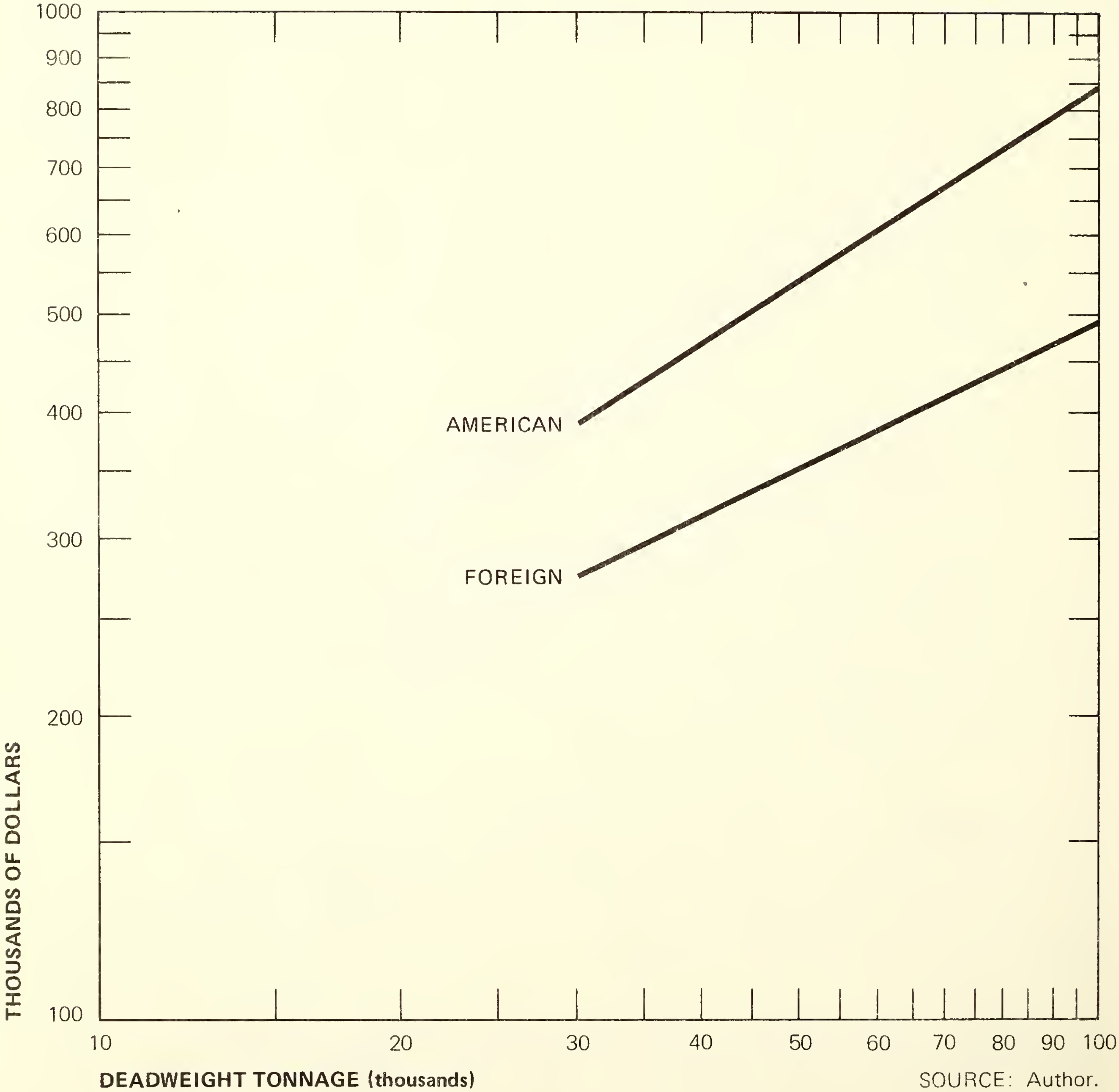
The estimated total costs for all maintenance and repair (M&R) not performed by the ship's crew are shown in Figure IV-D. Because of the wide variation in ship age, actual annual costs range from one-half of the value shown for new ships, to one-half again more for ships 25 years old. However the amounts shown, if set aside into a reserve for future M&R, should be adequate if interest is earned to keep up with inflation.

The U.S. ships would be serviced in U.S. yards, while the foreign ships used in nodule transport service may choose to drydock in Canada or elsewhere to keep M&R low. However parts availability problems and lack of experience of skilled repairmen working on foreign machinery, may both tend to increase the foreign ship costs to the relatively high levels shown on the graph.

Maintenance and repair cost increases due to additional equipment installed on foreign ships are expected to be balanced by the cost decreases resulting from higher quality construction, such as the improved hull and hold coatings, use of better materials in the accommodations, the more easily-cleaned holds, improved machinery, and automation.

Figure IV-C

TOTAL ANNUAL INSURANCE AND RESERVES COSTS



SOURCE: Author.

Additional M&R of the enlarged accommodations is estimated at 2% of the increased cost, foreign or domestic.

The M&R cost for the cargo handling equipment is assumed at an annual percentage of the installed cost for each ship type, foreign or domestic, as reported here:

Ship Type	Handling Equipment	M&R Annually
IV	Slurry, Load	1%
II	Conveyors, Load	2%
III	SelfUnloader	3%
VI	Cranes	3%
V	Slurry Discharge	4%

The last three cargo handling systems add substantial M&R costs, $100 to $300 thousand dollars annually to the American ship costs, an increase of almost 40% to half of the basic gearless ship M&R cost. The M&R for cargo handling category does include overhead-type costs associated with operating the cargo handling equipment, such as communications.

Overhead and Administration:

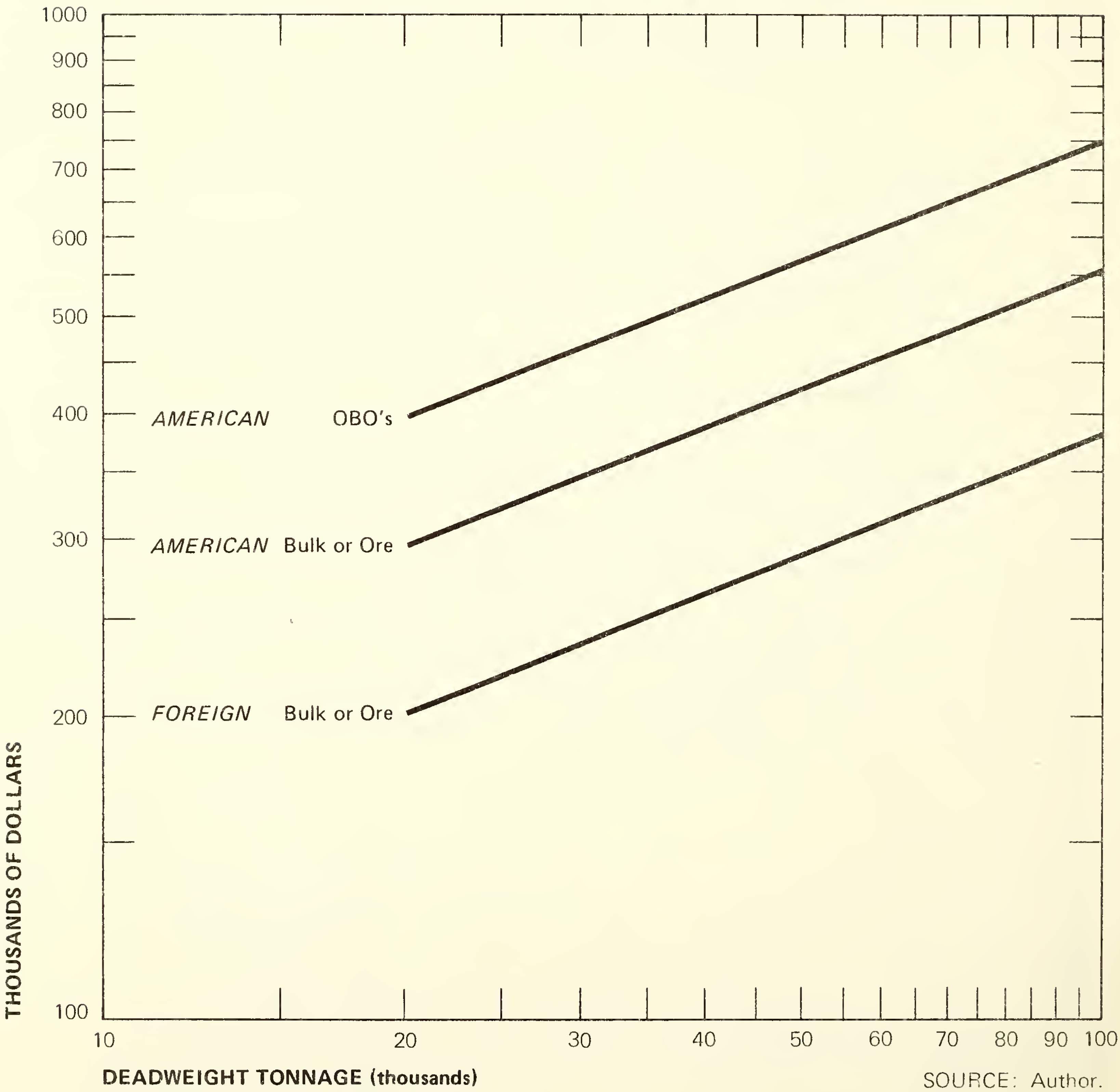
Management costs are largely a function of the number of ships operated. The values estimated in Figure IV-E assume three nodule ships of a ten ship fleet under a United States company's control, and three nodule ships of a 30 ship fleet under foreign control. Also, the ships are assumed to be on long-term charter or management contract for nodule transportation, not in the spot market. This cost category includes miscellaneous expenses not included in other categories. The carriage of mining ship crewmen, installation of additional equipment, and a high standard of design are expected to increase the costs of neither ship management nor of nodule transportation.

Transportation

Movement of crews to and from their home amd the transport ship will be a continuing expense. Crew rotation may be every six months at first class airfare for men working on American ships, to annual rotation of the entire crew of a foreign ship on a group air tour at the lowest cost. For the manganese nodule operation with an American ship crew signing on at the nodule discharge port, no expense should be involved. For foreign ships, about $800 per crew berth annually should be adequate for most countries. Since the total crew transportation amount is usually less than $30,000 per annum, closer estimates are not necessary.

Figure IV-D

TOTAL ANNUAL MAINTENANCE AND REPAIR COSTS



SOURCE: Author.

Fuel and Lubricating Oil

Underway consumption rates for fuel oils and lubricating oil by steam plants and by diesel engines at full power are shown in Figure IV-F. Steamship lube oil consumption is very small compared to diesel ship lube consumption, and is aggregated with boiler and generator fuel requirements for fuel oil. Steamships burn Bunker C costing only $12.66 per barrel, delivered. Fuel oil is 1500 sec. Redwood heavy diesel for diesel ships at $13.20 per bbl, the current OPEC price. Diesel lubricating oil is assumed at $1.75 per gallon or $73.50 per barrel, the U. S. Southern Pacific Coast port cost currently. Both U.S. and foreign ships pay the same unit fuel cost. However most American ships are steam powered, and foreign ships are diesel powered because of the net fuel saving from a 20% lower consumption rate but a 5% higher diesel fuel cost.

In-port fuel oil consumption rates for power generation are 10% of underway consumption for gearless ships, but 30% for tankers and OBOs pumping oil cargo in port. Therefore for ships equipped with self-unloaders, slurry discharge pumps and cranes (types III, V and VI), in-port fuel oil consumption was assumed at 30% of underway rates.

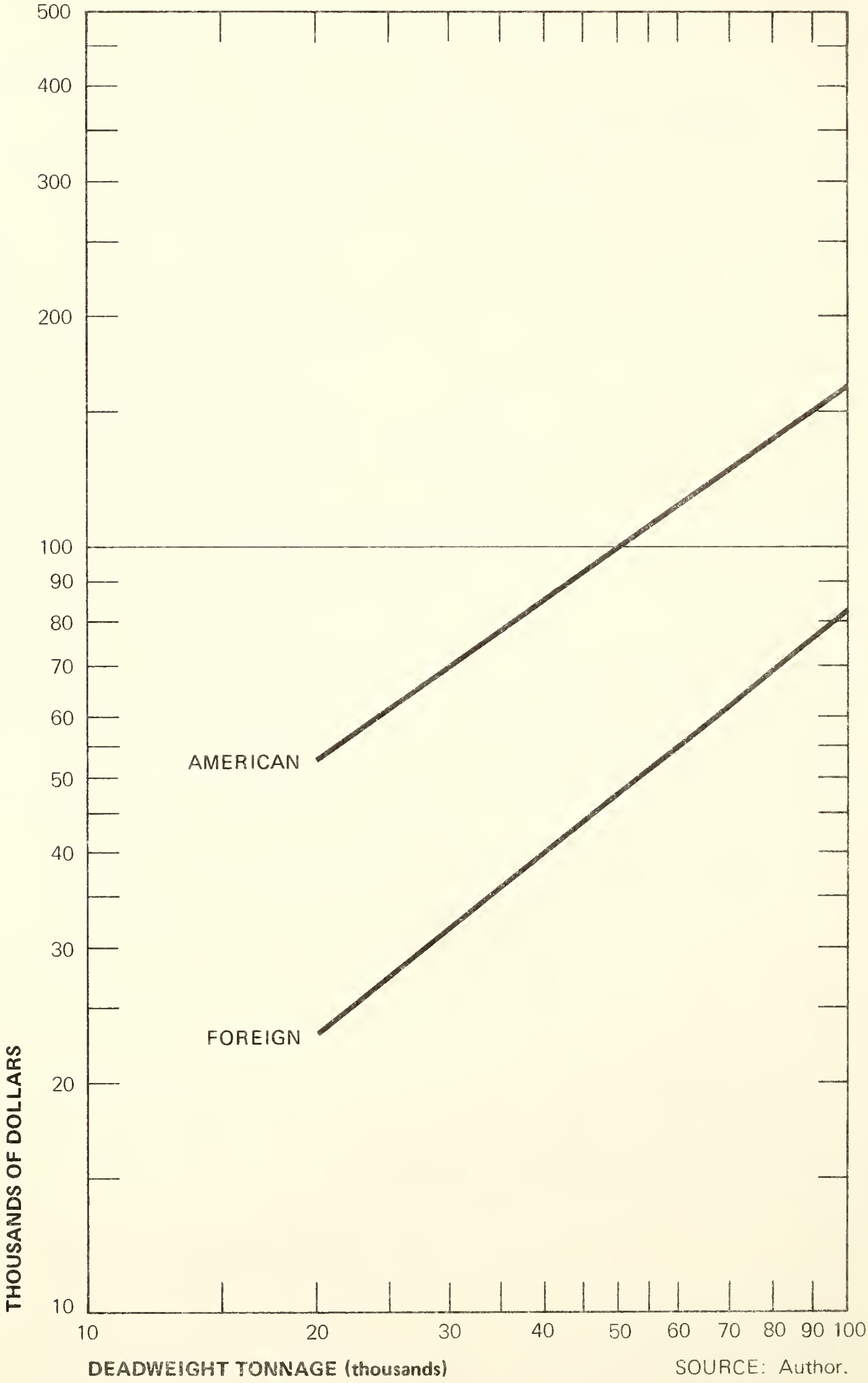
Port Charges

Port charges levied against nodule transport ships in the U. S. Pacific Coastal ports include dockage, pilotage, tug hire, line handling, watchmen, customs, launch hire and similar items. The size of the vessel determines many of these charges, each of which is quite small. Previous analyses have indicated that Gross Register Tonnage (GRT), a measure of the total internal volume of a ship hull, is a suitable parameter for estimating port charges. For most bulk ships, except ore-only designs, the Gross Register Tonnage is about 60% of deadweight tonnage for ships of 40 to 100 thousand DWT. The base charges for a one-day call include port entry and departure; additional days expenses are at a lower daily rate.

The Table IV-5 below summarizes the base cost for a bulk-ore ship port call at either ocean port or up an inland navigable channel to a deep water terminal; both situations apply on the Pacific Coast. The additional daily cost does not depend upon channel lengths to port.

Figure IV-E

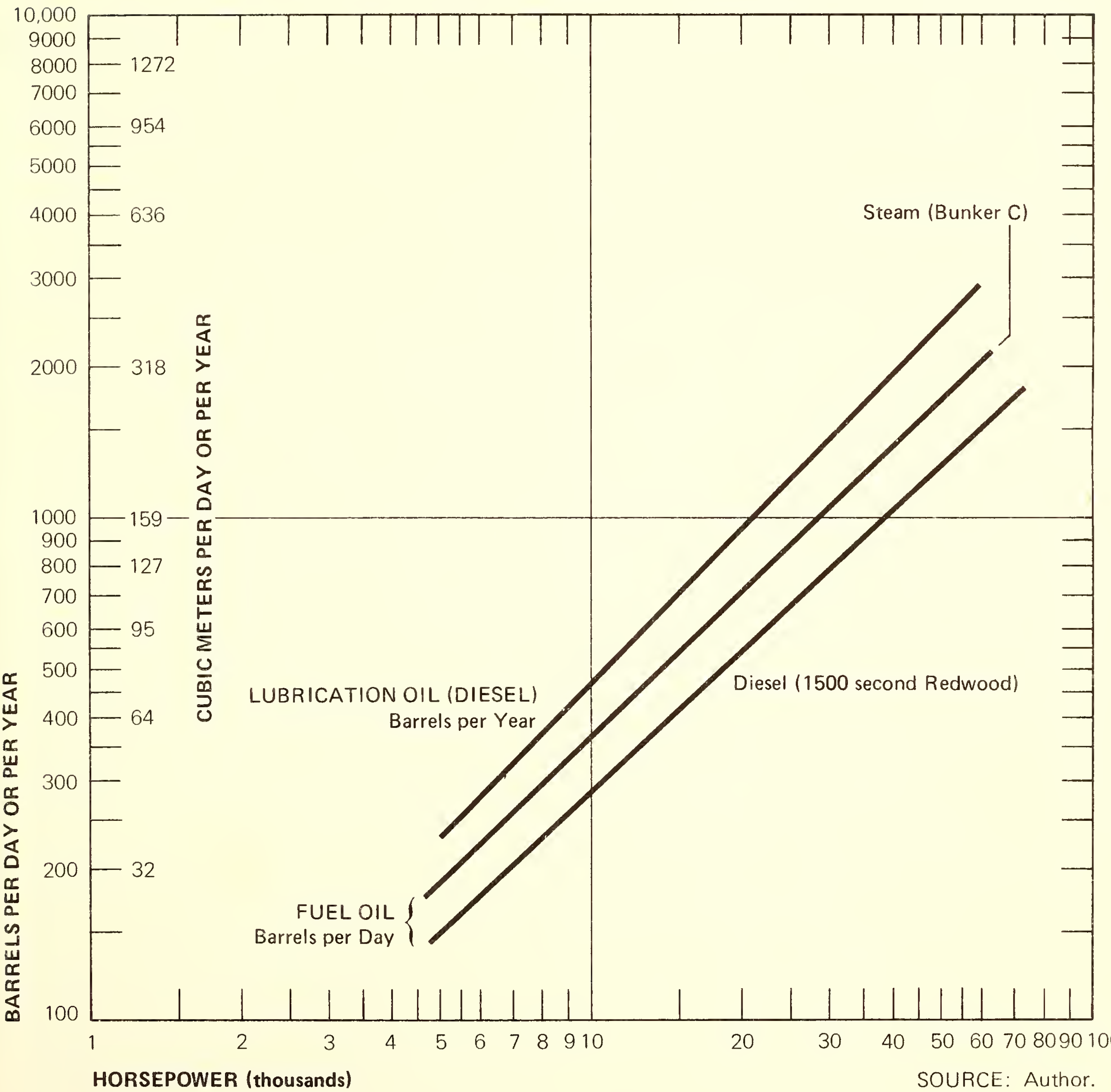
TOTAL ANNUAL OVERHEAD AND ADMINISTRATION COSTS



SOURCE: Author.

Figure IV-F

FUEL AND LUBRICATION OIL CONSUMPTION RATES



SOURCE: Author.

TABLE IV-5

PORT CHARGES
(Dollars)

	Deadweight Tonnage			
	40,000	55,000	70,000	85,000
Inland Port, up Channel, First Day	$6,600	$8,550	$10,350	$12,200
Ocean Port, First Day	4,300	5,300	6,400	7,500
Additional Daily Cost	1,100	1,470	1,830	2,190

The total operating costs for any vessel are estimatable from specifications of the precise voyages to be undertaken. The parameters for operating cost described here are applied to typical nodule transport voyages in the next Section V, where voyage proforma's are estimated.

V

VOYAGE SIMULATIONS

The performance and costs of the selected ships were estimated for nodule transport service in the Pacific Ocean. This section describes the typical ship routes, possible cargo handling systems, the ship schedules, and then the costs are summarized. The costs of different vessel flags are compared for the U. S. built and operated ships, foreign built and operated ships, and the mixed flag, foreign-built and U. S. operated ships.

The previous sections of this report described many of the assumptions and cost estimating procedures that are not repeated here.

Routes and Ports

The principal region of interest for deep sea mining by the consortia is a band from 5° to 18° North latitude, and from 110° to 180° West longitude, in the Pacific Ocean south of Baja, California and Hawaii to the International Date Line. The Deep Ocean Mining Environmental Survey (DOMES) is a major research project of NOAA at three sites near the center of this band, and the middle site is designated "B".

In the NOAA Phase I reports (Dames and Moore, 1977) the mining sites were assumed to be at DOMES Site B and the middle of the western boundary of the geographic area of principal commercial interest as specified in Table IV-I. Also, the ports of San Pedro, California, and Astoria, Oregon, were selected as representative of Southern and Northern U.S. Pacific coastal areas. These same locations are assumed in this analysis for evaluation of typical ship voyage costs. Table V-1 lists the locations, distances, and the ship round-trip voyage times. These were computed for the shortest (great circle) courses, at typical speeds laden and 15% faster when in ballast at 40% of DWT, and normal continuous power for ships with ram bows.

Allowance of 10% of the voyage times reported in Table V-1 was provided in the ship schedules to account for voyage route deviations, currents and delays. This minimal addition should be adequate for such a repetitive service in a relatively placid sea.

The slower speed typical of larger bulk ships would be subject to analysis by operators to ascertain the desirability of faster large ships with higher powers, especially for the longer voyages to more westerly mining sites.

TABLE V-1

SELECTED NODULE TRANSPORT VOYAGES

From	To	Distance+ (nautical miles)	Round Trip Voyage Time* (days) at loaded speed (knots)			
			15.5K	14.9K	14.5K	14.1K
DOMES Site B (11°42'N, 138°24'W)	Southern California	1,750	8.752	9.105	9.356	9.621
DOMES Site B	Pacific Northwest	2,275	11.378	11.836	12.163	12.508
Western Boundary (12°N,180°W)	Any West Coast Port	3,800	19.005	19.770	20.315	20.892

+No extra sailing distance is provided here; in computations 10% extra time is allowed for routing and currents.

*Ballast speed taken at 115% of loaded speed at normal continuous power with ram bow and 40% ballast. These vessel speeds are for the 40, 55, 70, and 85 thousand DWT typical ships.

Port and Ship Cargo Transfer Facilities

Two systems for handling nodules are examined for vessel costs, by conveyors and by slurry pumping. The analysis reported in Section III confirmed industry opinion that installing multiple shipboard nodule discharging equipment is relatively expensive, because two or more ships must be equipped with discharge gear that is also more difficult to maintain onboard than onshore. Therefore provisions have been assumed for either a nodule loading distribution conveyor, or a slurry receiving pipeline and dewatering, on a bulk-ore ship. For either method of loading, either method of discharge may be adopted, since the discharge equipment on shore is independent of the loading system. The higher cost OBO ship and more expensive self-discharging slurry or conveyor ships are not analyzed.

The effective transfer rates in long or metric tons per hour are shown on Table V-2. Effective slurry load or discharge rates are assumed to be 70% of the nominal rated capacity, and conveyor methods are expected to average 60% efficient. Equipment on the mining ship is assumed to be installed with

TABLE V-2

ESTIMATED NODULE HANDLING RATES AND TOTAL PORT TIME

	Ship Deadweight (DWT)			
	40,000	55,000	70,000	85,000
Handling Method	Average Transfer Rates (Long tons/hour)			
Load, Whole Nodule Conveyor	1,600	1,800	2,000	2,200
Load, Slurry Pumping	2,000	2,200	2,400	2,600
Discharge, Shore Excavator	1,500	1,800	2,100	2,400
Discharge, Shore Slurry Pumps	1,750	2,100	2,450	2,800
	Total Transfer Time at Sea (hours)			
Load, Whole Nodule	26.5	31.5	35.5	38.77
Load, Slurry Pumping by Mining Ship	22.0	26.5	30.25	33.42
	Total Port Time (Hours)			
Discharge, Shore Excavator	30.0	31.5	34.0	34.87
Discharge, Shore Slurry Pumps	24.57	27.57	29.71	31.32

rated capacity of about 2,700 tons per hour for loading of the smallest (40,000 DWT) ship, up to about 3,700 tons per hour for the largest (85,000 DWT). The mining ship stowage capacity for transfer, mining rates, and transfer rate are interrelated but were not analyzed in this study.

For discharge of dry, whole nodules, shore cranes rated at 1,000 tons per hour per unit with clamshell buckets, continuous bucket unloaders, or Hulett cranes, were assumed to be provided at one unit per each two ship laden holds. Shore based slurry pumping equipment handled by a crane was assumed for each of the laden holds, with each slurry discharge unit rated at 500 tons of solids per hour. Because of the overall performance efficiency noted above, the slurry system is slightly faster than conveying.

Total time at sea for loading may take about four hours longer than actual nodule transfer time, because of the approach, connect and disconnect time. Total port time would probably be about six hours longer than computed nodule discharge time. Fueling and repairs should be completed in the time available without extensions. The total sea transfer and port times are shown on Table V-2, for ships carrying 90% of their rated deadweight tonnage in nodule cargoes on the average voyage. Total nonsteaming times per round voyage range from 56.5 to 73.6 hours per trip for conveying methods, and almost ten hours less with slurry pumping.

Schedules and Performance

The sum of underway voyage times, laden and in ballast, and the transfer time from the mining ship at sea and in port, determine the total round voyage time. The transport ship can be fully utilized less than normally available because the mining ship will have time when it is not producing nodules. Therefore a useful transport ship year of 330 days was assumed, which would result in the number of voyages shown on Table V-3 for both slurry and conveyor handling methods. Under the assumptions made, little additional annual capacity (less than 4%) is provided by slurry methods of handling, as compared to conventional dry bulk conveying.

Ship cost when equipped for dry nodule loading by conveyors is a bit over one million dollars higher for conveyors than loading by slurry pipeline on American ships. Additional conveyor loading maintenance and repair and manpower costs slightly increase the conveyor cost difference over slurry loading. However these differences are less than 3% of the total yard costs.

TABLE V-3

NODULE TRANSPORT SHIP SERVICE*

	Deadweight Tonnage (Thousands)			
	40	55	70	85
SLURRY HANDLING				
Site B-Southern California				
Trips p.a.	28.53	26.90	25.41	24.85
Tons p.a. (thousands)	1,027	1,331	1,601	1,901
Site B-Pacific Northwest				
Trips p.a.	22.83	21.61	20.78	20.95
Tons p.a. (thousands)	822	1,070	1,309	1,534
Western Boundary-Either				
Trips p.a.	14.44	13.75	13.28	12.85
Tons p.a (thoudands)	520	681	837	983
CONVEYOR HANDLING				
Site B-Southern California				
Trips p.a.	27.54	26.11	24.65	24.17
Tons p.a. (thousands)	992	1,292	1,553	1,849
Site B-Pacific Northwest				
Trips p.a.	22,19	21.09	20.28	19.61
Trips p.a. (thousands)	799	1,044	1,277	1,500
Western Boundary-Either				
Trips p.a.	14.19	13.54	13.07	12.67
Tons p.a. (thousands)	511	670	824	969

*Assumes 330 working days annually, and 90% of deadweight tonnage represents the average nodule load.

Therefore both the slurry system and dry nodule conveyor methods with shore discharging were selected to demonstrate the relative transportation costs of nodule ships. Slurry is described first, and the raw nodule conveyor and shore conventional discharge are reported last.

The other systems would be more expensive; however this cost comparison does not include terminal equipment, land, storage and labor costs, nor mining ship costs for the same items. A systems analysis examining these elements probably will be performed for each mining consortium. Reports of analysis performed by the mining consortia indicate the slurry system described here is favored for implementation. However the conventional dry conveying and unloading cost results are shown at the end of this section.

Slurry Transport Ship Daily Costs

The daily charge for recovery of capital cost, allocation of annual operating expenses including maintenance and repairs of added equipment, and fuel costs, were computed from data fully presented in the preceding sections. The summary results are shown on Table V-4 for all four selected ship sizes equipped to load slurry at sea, for U. S. construction and operation; foreign construction and operation, and foreign-built for U. S. operation. The American-built ships are

TABLE V-4

SLURRY NODULE TRANSPORT SHIP DAILY COSTS
SLURRY LOADERS, AUTOMATED, 330 OPERATING DAYS
(Dollars per Working Day)

	Deadweight Tonnage (Thousands)			
	40	55	70	85
United States Built & Operated; Steam:				
At Sea	$27,383	$20,879	$33,833	$37,098
In Port	21,344	24,156	26,543	29,344
Profit Included	2,801	3,201	3,524	3,910
European Built, U.S. Operated; Diesel:				
At Sea	20,932	23,915	26,658	29,168
In Port	16,117	18,565	20,830	22,867
Profit Included	1,695	2,002	2,267	2,503
European Built & Operated; Diesel:				
At Sea	16,502	18,715	20,646	22,425
In Port	11,687	13,365	14,820	16,124
Profit Included	2,116	2,500	2,831	3,126

steam boiler and turbine powered, the others are diesel propelled and have a four man smaller crew at the same size and power. Total annual costs incurred over a 350 day manning period are to be recouped in 330 days of operation, indicating 20 days in active idle status.

The costs estimated for mixed ships imported into the United States requires some significant assumptions. These include the diesel propulsion M & R costs, the reduced manning on the diesel ship without increase in pay over comparably-manned steamships, and no application of duties for the importation of a commercial ship. However the other costs of a mixed ship are reasonably estimatable.

The Table V-5 below indicates the distribution of total daily costs for 70,000 DWT slurry loading nodule transport ships underway, under the three flag conditions. A relatively high proportion is for capital recovery, about half the total for U.S. built ships. The foreign vessels' relatively high fuel expenditure explains the constant attention by foreign operators to improved engine efficiency. The imported ship has a notably high proportion of costs for wages and benefits.

TABLE V-5

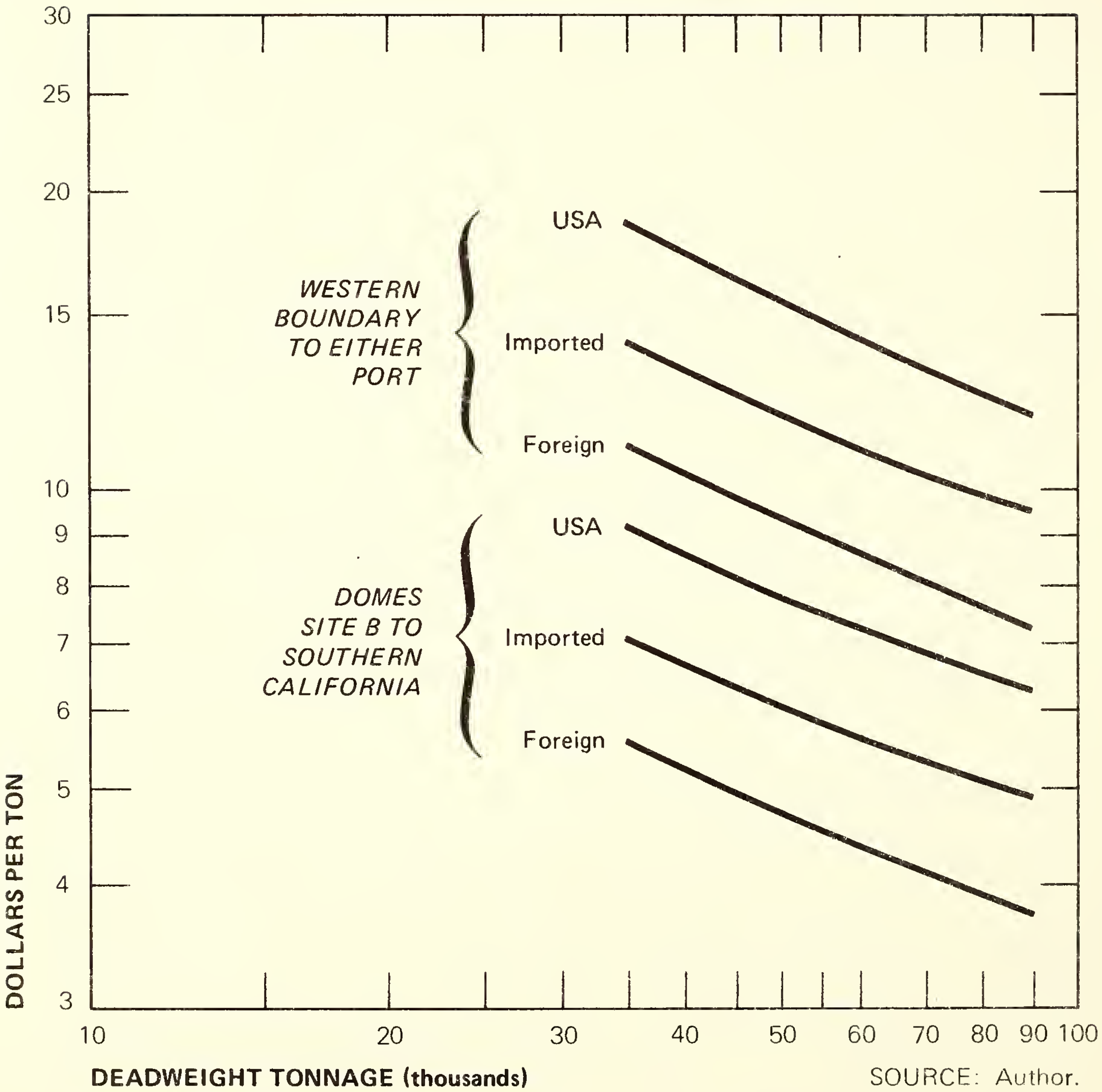
DISTRIBUTION OF UNDERWAY DAILY COST ELEMENTS
70,000 DWT, Slurry Loading Nodule Transporters
(Percentage of Total Daily Underway Costs)

Component	U. S. Ship	Imported Ship	Foreign Ship
Capital Recovery	49%	40%	43%
Fuel	24	25	31
Wages & Benefits	13	16	9
Insurance	6	7	6
Maintenance & Repair	4	6	5
All Other	4	6	6
Relative Total Costs	164%	129%	100%

However the 29% increase over the cheapest foreign ship in total daily underway cost for the imported ship, and the 64% increase for the U. S. ship, indicate a substantial margin of saving for the cheapest ship of two to five million dollars per year for the same transport capacity. The cost differences should extend for twenty years unless aggravated by even higher ship and fuel prices and wage differentials.

Figure V-A

NODULE SLURRY TRANSPORT COSTS: 1977



SOURCE: Author.

Slurry Transport Cost Comparisons

Figure V-A, or Table I-3 in the Summary, show the costs per metric or long ton of nodules computed for the DOMES Site B to San Pedro slurry movement, and for nodule transport from the Western Boundary to either San Pedro or Astoria. The smallest size ships were about 35% more expensive per ton than the largest size calculated, for every flag and distance. This result demonstrates again the economy of ship scale and cause of the insistent commercial demand for deeper navigation channels to marine terminals. However the extra costs of deeper channels and terminals, and of faster, larger terminals for larger ships, is not reflected in these costs. Clearly operators will choose to use fewer, larger ships when possible.

The foreign ship cost per ton, $8.07 in 70,000 DWT ships, is about 64% less than the U. S. ship costs at $13.21. The imported ship cost is 21% less than the American ship cost. The inverse computation results in foreign ships being 59% of U. S. cost, and for imported ships, 77% of U. S. ship cost.

Total costs of a 70,000 DWT ship per year are:

for foreign ships	$6,755,000,
for imported ships	8,738,000, and
for American ships	11,057,000.

The total differences of over $4.25 million per year, for ships with similar capacity in similar services are too large an amount to be negligible.

Conventional Handling System Costs

The costs estimated for daily operation of the bulk/ore ships equipped for conveyor loading at sea and shore discharge by conventional shoreside bucket equipment are shown on Table V-6. These daily costs are only a few hundreds of dollars per day more, because the ships are over 2% more expensive and carry one additional crewman as compared to the slurry loading ship described above. The distribution of daily cost elements is the same as for slurry nodule ships.

The cost results for DOMES Site B voyage to Southern California parallel those of the slurry method costs, but are 40¢ per tonne more for the smaller U.S. ships, to 15¢ per tonne more expensive for the largest, roughly 4-1/2% more expensive. The European ship example (Italian crew) is about 4% more expensive for dry conveying compared to slurry handling.

Again, the smallest ship costs one-third more per tonne than the largest, just as for slurry.

Also, the European built and operated ship costs are only 60% of the U.S. built and operated ship costs. Conversely, the U.S. ship costs two-thirds more than the foreign. These average values are almost exactly the same as reported for the slurry handling ships, and demonstrate the consistency of result that is expected of this type of computation from parametric data.

Similar cases can be computed for other voyages, handling methods, or nationalities of crew operation. However the same comparative results will be generated, and therefore more cost computations need not be reported. Even changing the major underlying voyage assumptions which apply to both U.S. flag and foreign ships will not materially alter the conclusions about relative costs.

TABLE V-6

DRY WHOLE NODULE SHIPMENT COST COMPARISON
(Conveyor loading, shore discharge)

	Ship Deadweight Tonnage			
	40,000	55,000	70,000	85,000
	(Dollars per wet tonne)			
Site B to Southern California				
U.S. Built and Operated, Steam	$9.046	$7.832	$7.174	$6.596
European Built and Operated, Diesel	5.445	4.742	4.347	3.965
Daily Operating Costs	(Dollars per Day)			
U.S.-Steam-At Sea	27,813	31,452	34,639	37,898
-In Port	22,310	25,103	27,754	30,580
-Includes Profit	2,864	3,278	3,615	4,008
European-Diesel				
-At Sea	16,805	19,801	21,034	22,849
-In Port	12,258	14,028	15,532	16,898
-Includes Profit	2,179	2,572	2,911	3,215

VI

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